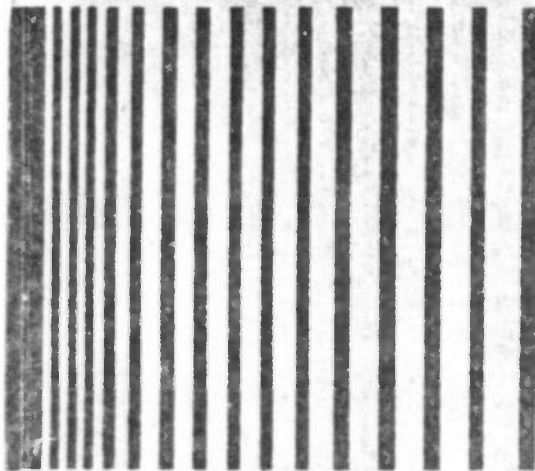


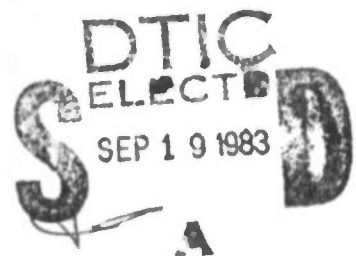
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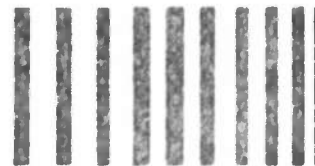
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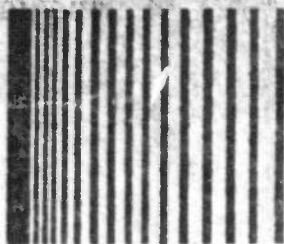
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# THE SHOCK AND VIBRATION DIGEST



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# SVIC NOTES

## INSTITUTE OF ENVIRONMENTAL SCIENCES ELECTS HENRY C. PUSEY FELLOW

Henry C. Pusey, Director, Naval Research Laboratory, Shock and Vibration Information Center, was elected to the membership grade of FELLOW in the Institute of Environmental Sciences. Mr. Pusey was honored "for invaluable sustained leadership in the development, coordination and dissemination of an international shock and vibration information base, in particular through his role as Director of Shock and Vibration Information Center."



Henry C. Pusey

Mr. Pusey has served the Institute as Region II Vice President, Manager Shock and Vibration Technical Committee, General Chairman, 1980 Annual Technical Meeting. He was the recipient of the IES Irwin Vigness Award for Shock and Vibration in 1974.

The presentation of the Fellow Award was made to Mr. Pusey at the Institute's 29th Annual Technical Meeting Awards Banquet, at the Marriott Hotel, Los Angeles, California, April 20, 1983.

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# EDITORS RATTLE SPACE

## THE IMPACT OF MICROPROCESSORS ON VIBRATION ENGINEERING

The advent of the inexpensive microprocessor has revolutionized the way we do vibration calculations today. Because of the complex mathematical nature of vibration theory, it is a natural application area for computers. The computing power of the microprocessor can be used to analyze many vibration problems thereby eliminating the need to resort to mainframe computers. The accessibility and convenience of microprocessors as opposed to mainframe computers means that large and very difficult problems can now be solved on site within minutes.

I believe that the microprocessor and programmable calculator have had a good influence on the engineer. Solution of an ever increasing number of problems on the computer has fostered a better understanding by the engineer of theory and the physical mechanisms that are described by theory. The strengths and limitations of the numerical processes used in computation can be better understood by engineers who apply them in small computers. The reason is that the average engineer now does some or all of his own programming.

The "black box" syndrome is no longer in effect. When engineers were solely dependent on mainframe computers and canned software there was more tendency to attempt to solve problems with a "black box" approach and less inclination or opportunity for innovation.

Computing is probably done less efficiently by engineers than by professional programmers, but the engineer is gaining a better physical understanding of mechanisms as he develops programs, and this is the essence of engineering.

R.L.E.

## INDUSTRIAL NOISE CONTROL: THE PAST THREE YEARS

R.J. Peppin\*

**Abstract.** *This paper surveys literature concerning industrial noise control over the past three years. Broad categories are presented because of the encompassing nature of the areas.*

Industrial noise control is one of the subfields in the area of noise control. Others include building acoustics, community noise, mechanical equipment (HVAC, plumbing) noise, and, sometimes, architectural acoustics. One way to identify industrial noise is to determine if it affects workers: if noise affects workers it can be defined as industrial. However, such a general definition encompasses a broad area because workers can be anywhere; even noise produced in the community or in buildings can affect workers. In the following discussion, therefore, it is assumed that industrial noise is noise affecting workers traditionally considered employed in such industrial areas as factories, refineries, and mills. Truck drivers, cooling tower maintenance workers, office workers, and pilots are not included in this classification.

The field of industrial noise control includes methods of prediction (analysis and modeling), methods of quantification (metrics, instrumentation, and measurement), and methods of abatement (usually in the form of case histories) that involve either source noise control, path noise control, or receiver control. Source noise control is usually the redesign or new design of equipment, processes, and materials. Path noise control consists of reverberation control of space, the judicious use of barriers and enclosures, and damping. Treatment of the receiver, such as the use of earmuffs or personnel enclosures, although traditionally considered a means of noise control, is actually a method of employee protection that is not truly noise control.

Every industry has numerous major noise sources, each of which can be common to many industries.

Thus, for example, refineries have diesel generators, furnaces, vents, pumps, and electric motors, most of which are also found in a can-manufacturing plant. Yet the latter type of plant can have noise sources caused by material handling systems that are often missing in refineries. To complicate matters, each major noise source is often composed of one or more interacting smaller sources, so that the noise produced by a machine such as a ball mill can consist of ball-to-ball impacts, ball-to-material impacts, ball-to-drum impacts, and gear tooth impacts, as well as the acoustical characteristics of the structure-borne and airborne paths. Therefore, even if the source of noise is the ball mill, the sum of many smaller sources combine to produce the noise thought to emanate from the mill.

Engineers and research workers involved in noise control do not usually specialize in a generic area such as source noise control. Rather, they often work in an industry- or process-specific area such as centrifugal fans, metal forming processes, refineries, or furnaces. Because the number of these areas is legion, the literature review that follows is partially based on a noise source categorization. One complexity of determining bounds in this literature review is the close relationship between sound and vibration. Because vibration reduction often results in a drop in noise level, papers on vibration control could also be considered part of noise control. To limit this review, therefore, I have attempted whenever possible to exclude vibration unless it is discussed as a part of noise control.

The field of industrial noise control gained momentum during the development and enforcement of the noise control requirement of the Occupational Safety and Health Act (Title 29 of the Code of Federal Regulations, 1910.95); such noise control is possibly on the decline at this writing (early 1983). Industrial noise control is based on empirical and

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theoretical science and engineering related facts; the effects of noise on people and the criteria associated with these effects are based on another branch of science or strongly political and economic motives, or both. As a result, it is difficult to state where noise control will be ten years hence. It is clear that work will be done in measurement techniques, instrumentation, and some theoretical noise control of various equipment, especially in critical areas or in progressive facilities. However, it is not clear that the strong force that has driven research and engineering will continue.

This review is the first dealing with industrial noise control in the *Digest* and thus covers a relatively large area. Even so, only the predominant literature of the last three years is included. Readers desiring historical literature should consult references and review citations to earlier works. Future reviews will be essentially noise-source specific. Literature in industrial noise control appears in refereed journals, trade magazines, magazines for the lay person, and conference proceedings.

### LITERATURE ON INDUSTRIAL NOISE CONTROL

One popular source of articles on industrial noise control is *S/V, Sound and Vibration* [1]. This controlled-circulation magazine contains a variety of articles on noise, many of which deal with industrial noise control. Most of the articles are written for individuals who deal with noise in their daily work; as a result, the articles can usually be read and understood by persons with some technical or academic training. The articles often include examples of solutions to noise control problems. Other magazines [2, 3] have occasional articles that are general in nature and do not provide generic fixes for noise control.

A popular journal in the United States is *Noise Control Engineering Journal* [4], originally called *Noise Control Engineering*. Published by the Institute of Noise Control Engineering [5] it is refereed and is meant for engineers. Relatively sophisticated analytical and experimental approaches are used in the many articles on industrial noise control.

Popular proceedings include those from two conferences sponsored by INCE, Noise-Con and Inter

Noise [6]. The proceedings usually contain many (usually more than 100) brief (approximately four pages each) papers that provide the most current reports of research in print. *Sound and Vibration* [1] publishes a proceedings of its yearly conference, Noisexpo. *The Journal of the Acoustical Society of America* [7] also publishes recent research as abstracts in programs for semiannual meetings. A journal published by the American Society of Mechanical Engineers [8] is the *Journal of Vibration, Acoustics, Stress, and Reliability in Design*. It contains articles either of the type previously carried by other ASME-sponsored journals or published as ASME preprints from sessions held at ASME conferences. Relevant preprints will not be eliminated by publication of the *Journal* but will probably be incorporated into more specialized publications.

*Journal of the Acoustical Society of America* [7] occasionally contains papers on noise control engineering, but they are usually theoretical treatments of rather esoteric problems. Two other journals, usually found only in academic or research libraries in the United States, [9, 10] contain readable articles that deal with noise control. The articles usually contain reports of results of theoretical work, experimental work, or both.

The *Shock and Vibration Digest* [11], issued monthly, contains abstracts of articles from most of the literature in the field. Approximately 130 publications are scanned; the relevant papers are of varying levels of sophistication. *Applied Mechanics Reviews* [12] contains critical reviews of articles, some related to noise control, usually at a basic mechanics level -- e.g., contact stresses, sound generation.

Other publications in the United States and abroad also contain relevant articles on noise control and range from sophisticated foreign language journals to trade magazines. They will be incorporated in a future review.

Other sources of product literature, handbooks, and technical reviews include manufacturers of materials, systems, and instruments. At the least these sources provide step-by-step approaches to noise reduction [13, 14] or sophisticated treatises on relevant topics [15]. One excellent how-to-book on noise control was published by the Department of Labor [16]. Although the present administration has decided to

not distribute this book, it can be found in an almost identical format [17] as part of a manufacturer's literature offering.

In the following paragraphs the diverse field of industrial noise control is categorized in discrete groups. The citations to the literature are not complete, but they are representative of the areas.

## **SURVEY OF PUBLICATIONS ON INDUSTRIAL NOISE CONTROL**

**Analytical and experimental approaches.** Industrial noise control is most efficiently accomplished during the design stages. When equipment in operation produces noise, measurement and analysis are usually necessary to develop an effective control.

Articles on analytical and experimental approaches range from general tutorials [18] and analyses [19, 20] to finite elements [21-25] and other methods for physical and analytical modeling and basic design [26-30]. Published work also includes methods of predicting the noise produced by machine elements in vibration [31, 32] and the close relationship between noise and vibration [33-38].

Some experimental work has been performed in the relatively new areas of time-series, cepstra, and coherence techniques [39, 40]. A potentially important analytical tool, the statistical energy analysis method, has been the subject of several publications [41-47]. The number of experiments in acoustic intensity and surface intensity techniques has increased in the last couple of years as indicated by the increase in commercial instrumentation available and the many articles published [48-60]. One of the more recent works in noise control deals with the renewed concept of active noise control; i.e., cancellation of existing sound fields by generating similar fields [61, 62].

**Materials and components.** A number of publications on noise control have dealt with specific areas of materials investigation and applications and techniques to control noise of specific components. Topics include insulation [63, 64] and barriers [65, 66], as well as general issues in the areas of materials [67-73] and their properties, including transmission loss [74, 75]. Pipe noise control was a

topic of research [74, 76] as was an associated noise control technique, lagging [77]. In the area of mechanical components of noise, especially contact stresses and impact, several articles have treated transmission and gears [29, 78-82] and bearings and rollers [83, 84].

**Pneumatic and hydraulic noise.** Pneumatic- and hydraulic-induced noise can be considered a distinct group because the noise is often not produced by structural vibration but by fluid turbulence. Turbulence usually sets the containing structure into motion and causes the structure to be a secondary source. Most of the articles in the area of pneumatic noise have dealt with heavy fans [85-89], mufflers and silencers [90-98, 175], valves [99-102], and combinations of components [98, 103-108]. Papers on hydraulic and other fluid-borne noise emphasized cavitation [109], pumps [110-112], and silencers [113]. Some papers discussed fluid power abatement in general [114-116].

**Specific noise sources.** Emphasis in the practice of noise control concerns the specific tools or processes necessary to solve a particular problem. Concepts of valve noise control can often be used in generic solutions for products and processes with valves; techniques to control saw noise, however, are limited to the class of equipment to which a technique is applicable. Similarly, the technology resulting from developing methods to solve systems noise -- for example, from a specific metal, chain driven, conveyor belt -- cannot usually be applied either to other types of systems or to other systems of similar construction. In the first case no technology transfers are applicable; in the second case site and installation peculiarities tend to make solutions for one system not applicable to another.

The general field of material handling has been treated [84, 117, 118], as have several industry-specific areas. For example, the textile process was well-represented [24, 119 - 124] as were printing processes [125]. Publication topics in the heavier industries included mining [126, 127] and power plants [40, 128-130].

One common tool that has been studied in the past few years in an attempt to control noise is saws, both circular saws and chain saws [131-137]. Other tools that have been studied are rock drills and

other percussive tools [108, 127, 138-140], engines [141-144], and transmissions [80, 81, 145]. Other industry-specific equipment, such as furnaces and burners [146-150], metal working and impact processes [23, 28, 117, 151-163], and hammer mills used for material reduction [164], have been studied. Several articles had to do with general concepts of noise control programs [26, 128, 165-173].

**General noise control techniques.** Some of the more specific methods of noise control have been discussed in articles dealing with damping [67, 174, 176] and noise enclosures [157, 177-180] including pipe lagging [77]. A yearly compendium was published for potential buyers of noise control systems [181-183], and a published search [184] contains general information on noise control.

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# **LITERATURE REVIEW:**

**survey and analysis  
of the Shock and  
Vibration literature**

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

This issue of the DIGEST contains articles about instability of circular cylinder arrays in cross flow and nonstationary resonance oscillations.

Dr. S.S. Chen of Argonne National Laboratory, Argonne, Illinois has written an article on the developments in dynamic instability of circular cylinder arrays subjected to cross flow. The review presents a summary of progress since 1980. Mathematical models, experimental data, stability criteria, design guidelines, and future research needs are discussed.

Dr. B.N. Agrawal of INTELSAT, Washington, D.C. and Dr. R.M. Evan-Iwanowski of Syracuse University, Syracuse, New York have written an article describing nonstationary oscillations in combination resonances, factors affecting nonstationary responses, and applications and unsolved problems of nonstationary responses.

1

# INSTABILITY OF CIRCULAR CYLINDER ARRAYS IN CROSS FLOW

S.S. Chen\*

**Abstract.** *Developments in dynamic instability of circular cylinder arrays subjected to cross flow has been exciting in the past several years. This review presents a summary of progress since 1980; mathematical models, experimental data, stability criteria, design guidelines, and future research needs are discussed.*

Developments in dynamic instability of circular cylinder arrays subjected to cross flow have been concerned in recent years with heat exchanger tube failures due to dynamic instability. Considerable literature has been developed to document service failures [1-3]; analytical and experimental studies are being made to explain complicated instability phenomena. Progress in this area up to 1979 has been presented in a previous review [4]. The present review describes mathematical models, experimental data, stability criteria, design guidelines, and future research needs; the period between 1980 and 1983 is covered.

## MATHEMATICAL MODELS AND STABILITY CRITERIA

The three important parameters used in the stability criteria are mass per unit length  $m$ , natural frequency

$f$ , and damping ratio  $\zeta$ . For a cylinder array vibrating in flow, the definitions of these three parameters vary widely. These parameters can be defined under the following four conditions:

- In vacuum: system parameters are measured in vacuum (practically, in air); the effect of the surrounding fluid is ignored.
- In quiescent fluid - uncoupled vibration: system parameters are measured for an elastic cylinder vibrating in a fluid; the surrounding cylinders are rigid. The coupling effect of fluid is not taken into account.
- In quiescent fluid - coupled vibration: system parameters are measured for an array of cylinders vibrating in a fluid; the coupling among different cylinders due to fluid is included.
- In flow: system parameters are measured in flow; in general, they are dependent on the flow velocity.

These parameters are summarized in Table 1.

A summary of mathematical models is presented in Table 2 [5-15]. With the exception of the original model developed by Connors [5] and analyzed by Blevins [6, 7], all of the models were published

Table 1. Effective Mass, Natural Frequency, and Modal Damping Ratio in Different Conditions

Parameters	In Vacuum	In Quiescent Fluid		In Flow
		Uncoupled Vibration	Coupled Vibration	
Effective Mass ( $m$ )	$m_v$	$m_u$	$m_c$	$m_f$
Natural Frequency ( $f$ )	$f_v$	$f_u$	$f_c$	$f_f$
Modal Damping Ratio ( $\zeta$ )	$\zeta_v$	$\zeta_u$	$\zeta_c$	$\zeta_f$

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Table 2. Models for Stability of Tube Arrays in Cross Flow

Author	Name of Instability	Instability Mechanism	Dominant Fluid Force	Instability Criterion	Parameters Used in Stability Criterion	Method to Obtain Stability Criterion
Connors [6]	Fluidelastic vibration	Displacement mechanism	Fluidelastic-stiffness force	$\frac{U}{fD} = \alpha \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.5}$	$f_u, m_u, \zeta_u$	Energy consideration of a single cylinder and experimentally measured mode shape
Blevins [6, 7]	Fluidelastic whirling	Displacement mechanism	Fluidelastic-stiffness force	$\frac{U}{fD} = \alpha \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.5}$	$f_u, m_u, \zeta_u$ or $\zeta_f$	Equations of motion for cylinder rows with assumed mode shapes
Tanaka et al [9, 10]	Fluidelastic vibration	Displacement and velocity mechanisms	Fluid dynamic force including fluidelastic-stiffness force and flow-velocity-dependent damping force	Light fluid: $\frac{U}{fD} = \alpha \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.5}, (P/D = 1.33)$ Heavy fluid: $\frac{U}{fD} = \alpha_1 (2\pi \zeta^*)^{\alpha_2} \left( \frac{m}{\rho D^2} \right)^{\alpha_3}, (P/D = 1.33)$ $\frac{U}{fD} = \alpha_1 \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.75}, (P/D = 2.0)$	$f_v, m_v, \zeta_v$	Equations of motion using measured fluid-force data
Chen [11, 12]	Dynamic instability: 1. Fluid-damping-controlled instability. 2. Fluidelastic stiffness-controlled instability	Displacement mechanism and/or velocity mechanism	Fluidelastic-stiffness force and flow-velocity-dependent damping force	Light fluid: $\frac{U}{fD} = \alpha \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.5}$ Heavy fluid: $\frac{U}{fD} = \alpha_1 (2\pi \zeta^*)^{\alpha_2} \left( \frac{m}{\rho D^2} \right)^{\alpha_3}$	$f_v, m_v, \zeta_v$ or $f_c, m_c, \zeta_c$	Equations of motion using measured fluid-damping and fluidelastic-stiffness forces
Price and Paidoussis [14]	Fluidelastic instability	Displacement mechanism	Fluidelastic-stiffness force (flow-velocity-dependent force taken into account partially)	$\frac{U}{fD} = \alpha_1 \left[ 1 + \left( 1 + \alpha_2 \frac{2\pi \zeta^* m}{\rho D^2} \right)^{0.5} \right]$	$f^*, m^*, \zeta^*$	Equations of motion using measured fluid-stiffness forces
Lever and Weaver [15]	Fluidelastic instability	Velocity mechanism	Flow-velocity-dependent damping force	$\frac{U}{fD} = F \left( \frac{2\pi \zeta^* m}{\rho D^2} \right)$	$f^*, m_u, \zeta^*$	Equation of motion of a single cylinder among a rigid cylinder array

\*Not clearly specified. In most cases, these parameters are defined as follows:  $m$  = mass or mechanical mass;  $f$  = cylinder natural frequency; and  $\zeta$  = cylinder damping ratio or mechanical damping ratio

$\alpha, \alpha_1, \alpha_2, \alpha_3$  = different equations denote constants with different values in different equations;  $F$  denotes a function.

$U$  = flow velocity;  $D$  = cylinder diameter;  $\rho$  = fluid density.

in the last few years. Table 2 shows that these models are not in agreement in several respects: instability mechanisms, stability criteria and system parameters, and equations of motion.

**Instability mechanisms.** Two basic instability mechanisms have been discussed by Chen [11, 12]: velocity mechanism and displacement mechanism. With the velocity mechanism, or fluid-damping-controlled instability, the dominant fluid force is proportional to the velocity of the cylinders. The fluid-damping force depends on the reduced flow velocity and can act as an energy-dissipation mechanism or an excitation mechanism for cylinder oscillations. When the fluid-damping force acts as an excitation mechanism, system damping is reduced. After the modal damping of a mode becomes negative, the tubes are no longer stable.

With displacement mechanisms, or fluidelastic-stiffness-controlled instability, the dominant fluid force is proportional to the displacements of the cylinders. The fluidelastic-stiffness force can affect both natural frequencies and modal damping. As flow velocity increases, the fluidelastic-stiffness force can reduce modal damping. When the modal damping of a mode becomes negative, the cylinders become unstable.

Before 1980 the displacement mechanism was used exclusively; therefore, instability was attributed to the fluidelastic-stiffness force. When instability is attributed to the displacement mechanism, coupling of the fluidelastic-stiffness force and the neighboring cylinders is a requirement for instability. Before 1980 it was assumed that a single elastic cylinder among an array of rigid cylinders would not become unstable even though experimental results showed the contrary; no plausible explanation was given. Chen [11, 12] used Tanaka's fluid-force data [8-10] to show that both the displacement mechanism and the velocity mechanism are important. Discrepancies among different models can be resolved reasonably well using the two mechanisms.

**Stability criteria and system parameters.** Table 2 shows that different investigators have developed different stability criteria and used different parameters. In some cases the system parameters are not defined in sufficient detail or are used without justification.

**Equations of motion.** Among the approaches used to solve the equations of motion are a single equation of motion [5, 15], multiple equations of motion with assumed modes [6], and general solution of multiple equations [8-14].

The merits and deficiencies of each model can be summarized as follows:

- Quasi-static models (Connors, Blevins, and Price and Paidoussis). These models are applicable only for fluidelastic-stiffness-controlled instability. Although flow-velocity-dependent forces have been considered partially in some models, they are not applicable to fluid-damping-controlled instability.
- The analytical model (Lever and Weaver) requires only three empirical constants but is based on the velocity mechanism only. The model has been used to demonstrate the existence of the jump phenomenon in critical flow velocity at a certain value of the mass-damping parameter and the observed characteristics of cylinder arrays in heavy fluids. The model does not include the coupling effect of the fluidelastic-stiffness force. For light fluid, it predicts that the critical flow velocity  $U/fD$  is proportional to the first power of the mass-damping parameter; this is not in agreement with published experimental data.
- The general semi-analytical model (Chen and Tanaka) requires a significant amount of measurement or computation to determine fluid-force coefficients but predicts very well all the observed characteristics of instability for both light and heavy fluids, including the jump phenomenon and multiple stable and unstable regions [11-13].

At this point in time, the general semi-analytical model provides the most insight into instability phenomena.

Models not listed in Table 2 include a quasi-static model [16] that is basically an extension of Blevins' model.

## EXPERIMENTAL STUDIES

Because of the difficulty in predicting critical flow velocity under different conditions, experimental

studies have been conducted in various countries and can be grouped in several areas: stability constants, direct comparison with analytical results, and effects of different system parameters.

**Stability constants.** In addition to the analytical and semi-empirical stability criteria given in Table 2 are various stability criteria that have been proposed based on experimental data. Most of these criteria can be grouped into two classes:

- The critical flow velocity  $U/fD$  is a function of the mass-damping parameter

$$\frac{U}{fD} = \alpha_1 \left( \frac{2\pi m \xi}{\rho D^2} \right)^{\alpha_2} \quad (1)$$

- The critical flow velocity is a function of mass ratio  $(m/\rho D^2)$  and damping  $(2\pi \xi)$

$$\frac{U}{fD} = \beta_1 \left( \frac{m}{\rho D^2} \right)^{\beta_2} (2\pi \xi)^{\beta_3} \quad (2)$$

These equations have been adopted by various investigators [9, 10, 13, 17-21].

Extensive test programs have been conducted by several investigators. Heilker and Vincent [17] have presented the results of tube arrays in water and simulated two-phase flow for various layouts. The stability criterion equation (1) with  $\alpha_2 = 0.5$  is used; in their tests the tightly packed triangular pitch arrays are the most susceptible when the instability constant is  $\alpha_1 = 5.0$ .

Soper [18] has described a systematic study of the effect of tube layout on the instability constant for 16 tube bundles based on equation (1) with  $\alpha_2 = 0.5$ . Results show that the instability varies by a factor of three over the range of tube layouts tested.

Chen and Jendrzejczyk [19] presented experimental data for 12 different arrays of varying spacing, geometries, mass ratio, damping, and detuning in water flow. The empirical constants based on their test data and published results are  $\alpha_1 = 4.51$  and  $\alpha_2 = 0.52$ . Based on equation (1) the instability constant of tests on nine tube layouts with both metallic and plastic tubes does not vary much from  $\alpha_1 = 2.5$  with  $\alpha_2 = 0.5$  [20].

Other investigators emphasize different aspects of the problems; e.g., equation (2) has been used to establish the following constants for square arrays [9, 10]:

for pitch-to-diameter ratio of 1.33,

$$\frac{U}{fD} = \alpha_1 \left( \frac{2\pi m \xi}{\rho D^2} \right)^{0.5}, \text{ low density fluid}$$

$$\frac{U}{fD} = \alpha_1 \left( \frac{m}{\rho D^2} \right)^{1/3} (2\pi \xi)^{0.2}, \text{ high density fluid}$$

and for pitch-to-diameter ratio of 2.0

$$\frac{U}{fD} = 3.0 \left( \frac{2\pi m \xi}{\rho D^2} \right)^{0.75}$$

Results of triangular and square arrays for different pitch-to-diameter ratios in water and air-water two-phase flows have been reported [21]. Equation (1) was used to correlate the data.

**Direct comparison with analytical results.** The semi-analytical models (see Table 2) of Chen [12] and Tanaka [8-10] can provide detailed instability characteristics, such as oscillation frequency and mode at instability, as well as critical flow velocity. Experiments have been conducted by Chen and Jendrzejczyk [13, 22] and Tanaka [8-10] to verify their analytical solutions. Theoretical results and experimental data are in good agreement. Experimental data of Chen and Jendrzejczyk have verified the following conclusions:

- Two distinct instability mechanisms exist: fluid-damping-controlled instability and fluid-elastic-stiffness-controlled instability.
- Multiple stable and unstable regions exist in tube rows, and a jump occurs in the critical flow velocity at a certain value of the mass-damping parameter.
- The effect of detuning depends on instability mechanisms and the amount of detuning. Detuning is important for fluidelastic-stiffness-controlled instability.
- Different stability criteria should be used for large and small mass ratios.

Tanaka's data also agree with his analytical results [8-10].

**Effects of different system parameters.** The critical flow velocity is affected by many parameters, including detuning, upstream turbulence, nonuniform flow distribution, cylinder layout, mass ratio and damping, and support clearance. Some of these effects are qualitatively known; however, most of them are still difficult to evaluate quantitatively.

The frequency variation of a cylinder array in a vacuum is called detuning. When a cylinder array is submerged in a fluid, all of the cylinders are coupled by the fluid. The natural frequency of each cylinder in a vacuum must be known in order to define detuning. In general, the detuning of a cylinder array increases the critical flow velocity. In a water-loop test, Chen and Jendrzejczyk [23] demonstrated the effect of detuning on fluid-damping-controlled-instability. They showed that an elastic tube surrounded by rigid tubes in water flow can lose stability; the motion is predominantly in the lift direction. This agrees with the theory that a single elastic tube in a rigid square array can lose stability by a fluid-damping force in the lift direction [11, 12]. Other experimental data [20, 22] and analytical results [9, 13] are basically in agreement with those of Chen and Jendrzejczyk [23].

Tests with differences in streamwise and transverse frequencies ranging from 6.3 and 57% for a rotated triangular array with a pitch ratio of 1.375 were conducted by Weaver and Koroyannakis [24]. They found that the critical reduced flow velocity based on the lower frequency increased only slightly above that of the symmetric case; it was about 20% higher than the velocity for tubes with identical stiffness in the transverse and streamwise directions. The effect was essentially independent of the difference in frequency and direction of the lower frequency relative to flow. Note that the results apply only to a particular tube arrangement. Effects are not the same for different tube arrays. For example, for a tube row in water flow the lowest critical flow velocity is associated with the out-of-phase mode in the lift direction [22]. In this case an increase in the natural frequency in the drag direction will have little effect on critical flow velocity.

Upstream turbulence can affect critical flow velocity. Wind-tunnel experiments [25, 26] have shown that

turbulence causes initiation of fluidelastic instability to shift to higher flow velocities. Gorman [27] carried out tests in water for typical heat-exchanger tubes. He found that the existence of upstream grids and screens had no appreciable effect on the critical liquid approach velocity. However, other wind-tunnel experiments [28] have shown that turbulence tends to reduce critical flow velocity. A water-tunnel test has been used to resolve the discrepancy [19]; turbulence can stabilize or destabilize the tube array depending on the characteristics of the turbulence. This conclusion was verified by Soper in wind-tunnel tests [29]. In practical situations turbulence characteristics are not known and are difficult to account for.

In general, flow velocity is not uniform either in the axial direction along the cylinder or perpendicular to the cylinder. Most experiments are conducted for uniform flow. In practice, however, nonuniform flow distribution must be considered. Connors [30] has shown that the skimming flows created in the vicinity of inlet-nozzle impingement plates can cause instability; the critical flow velocity depends on cylinder pattern and spacing and on the clearance between the cylinder array and the wall. In a large cylinder array, the cylinders do not become unstable at the same time; this phenomenon has been attributed to nonuniform flow distribution and other effects.

Empirical correlations have been developed for the case in which an entire cylinder length is subjected to the same flow velocity. In many structural components or experiments, however, the flows are not uniform. A general practice has been to reduce the general case of nonuniform flow to the ideal case of uniform flow. An equivalent uniform flow velocity is defined by

$$U_e = \frac{\int U^2(z) \psi_m^2(z) dz}{\int \psi_m^2(z) dz} \quad (3)$$

where  $\psi_m(z)$  is the  $m$ th orthonormal function of the cylinders. Equation (3) has been used frequently [19, 28, 30]. It is applicable for high reduced flow velocity [12, 13] but is not strictly applicable at low reduced flow velocity.

The critical flow velocity depends on cylinder layout. Systematic studies have been conducted for different

cylinder arrays [17-21]. Available experimental data published up to 1981 have been compiled [34] for five different cylinder arrays: cylinder rows, square arrays, rotated square arrays, triangular arrays, and rotated triangular arrays. For practical pitch-to-diameter ratios, the effect of pitch-to-diameter ratio for square and rotated triangular arrays is not as important as other patterns.

Water tunnel experiments have been conducted on a triangular array of tubes with a pitch ratio of 1.5 [35]. The critical flow velocity for the triangular array was about twice that of the rotated triangular array. However, the critical flow velocity for triangular array was very sensitive to incident flow direction.

The mass ratio of a cylinder to the displaced mass of fluid and cylinder damping are two important parameters in determining critical flow velocity. Experiments have been conducted to study the effects of these two parameters. One of the following methods has been used: (1) placing the same cylinder array in air and water flow [9, 36] and in water and air-water two-phase flows [17], (2) using a different set of cylinder mass for the same array [9, 13, 38], and (3) varying cylinder damping for the same array [13, 19, 22]. Experimental data are in agreement with results based on the semi-analytical theory. In air flow, according to the semi-analytical theory [13] and experimental data, the mass ratio and damping can be combined as a single parameter and the stability criterion expressed in equation (1) is applicable. However, in liquid flow mass ratio and damping must be treated as two independent parameters; in this case the stability criterion expressed in equation (2) is more appropriate.

Cylinder response characteristics vary significantly with cylinder-to-support clearance. In turn, the effective clearance is a function of the initial mechanical fit up, tolerances, thermal expansion, and steady fluid forces. In the past cylinders supported by baffle plates have been treated as beams on knife-edge supports. This assumption is reasonable so long as the clearance between cylinder and support plate is small. When the support clearance is relatively large, the cylinder rattles around in whatever space is available. The supports cannot act as nodal point until they are impacted and significant response in theoretically restrained modes occurs [39]. Although

the clearance does not significantly affect the natural frequencies for modes in which support plates correspond to nodal points, it has the effect of increasing the critical flow velocity [40]. The interaction of cylinders with support plates in cross flow is fairly complex and is currently being studied.

**Fluid force.** Fluid forces acting on rigid and moving cylinders are measured using pressure transducers [20, 41], strain gauges [8-10], and fluid-force transducers [42]. The pressure for rigid and moving cylinders has also been measured [20]. The pressure obtained for a rigid cylinder has been analyzed to obtain frequency spectra, correlation length, and rms force coefficient. The pressure for a moving cylinder is similar to that of a rigid cylinder but also contains a pure tone spike at the frequency of cylinder vibration. This pure tone spike corresponds to the motion-dependent fluid force that is important for stability. Similar measurements have also been made by other workers [41].

Data from pressure transducers must be integrated to obtain the resultant fluid force. Direct measurements of fluid forces have been made [8-10, 42]. In one case [8-10] the cylinder strain was measured and the fluid force based on cylinder motion was calculated. In the other case [42] the resultant fluid force was measured directly using a force transducer.

Fluid-force data associated with a moving cylinder [8-10] has been used to calculate fluid-damping and fluidelastic-stiffness coefficients as functions of the reduced flow velocity [12]. These coefficients can be used to calculate the critical flow velocity.

## DESIGN CONSIDERATIONS

Various design guidelines have been proposed to evaluate heat transfer equipment [33,34,43,44]. In most cases a single criterion has been used for both light and heavy fluids and for all cylinder layouts. Chen [34] used his semi-analytical model to compile available experimental data for different cylinder patterns and different criteria for light and heavy fluids. In general, the experimental data obtained for light fluid agree well. The significant scattering of data that occurs in heavy fluid has been attributed to various causes: using different system parameters (see Ta-

ble 1), difficulty in defining the critical flow velocity, different mass ratio and damping, and differences in interpretation of data.

Design guidelines are useful in the assessment of a preliminary design. In many cases a scaled model or full scale of a sector are needed for design verification to assure that dynamic instability will not occur. For example, a test has been conducted on a half-scale sector model of a steam generator helical coil tube bank [45]. In addition, certain features are difficult to account for in the general stability criteria and must be considered [39, 40]. There are very few cases in which complete fluid force data are available and detailed analyses can be made [46].

Most data for simple test sections are obtained under laboratory conditions; questions are raised as to whether these data are applicable to real heat exchangers. To evaluate and improve prediction methods and design criteria a specifically built and instrumented, industrial-type, shell-and-tube heat exchanger has been tested to obtain tube vibration data under controlled conditions [47]. Data generated from tests are being made available to researchers and engineers for use in evaluating and improving predictive methods and design guides.

### CONCLUDING REMARKS

Significant progress has been made in the past few years on the subject of instability of circular cylinder arrays in cross flow. The three major accomplishments are as follows:

- Two instability mechanisms have been recognized: fluid-damping-controlled and fluidelastic-stiffness-controlled instability. Although different investigators are still not in agreement on the mechanisms, it is clear that the fluid force associated with the quasi-static displacement mechanism proposed in 1970 is not the only one that contributes to instability.
- In light fluid mass ratio and damping can be combined as a single parameter; the exponent of the mass-damping term is 0.5. In heavy fluid the two parameters must be treated independently. Stability criteria in light and heavy fluids also differ.

- Experimental and analytical techniques have been developed to characterize and predict instability phenomena; theory and experimental data are in agreement.

Dynamic instability of cylinders in cross flow has been an area of recent progress. Future studies are expected to focus in the following areas:

- Mathematical models and stability criteria: the analytical model [15] is useful for examining instability phenomena qualitatively; it is doubtful that such a model can be improved to predict details of instability characteristics. The quasi-static model [5, 6, 14] is useful in certain parameter ranges but is not always applicable. The semi-analytical method [8-10, 11-13] appears promising for predicting detailed characteristics; if numerical techniques can be developed to calculate fluid-damping and fluidelastic stiffness coefficients, this method could become very powerful.
- Fluid forces: fluid-force components are key factors in the prediction of critical flow velocity. Both experimental measurements and numerical calculations of fluid forces are needed to improve prediction techniques.
- Flow field: understanding the flow field around cylinder arrays oscillating in flow is important. Flow visualization and measurements of local pressure and flow velocity will allow identification and quantification of important system parameters.
- Effects of different system parameters: stability under some special conditions, such as nonuniform flow and support clearance, are also important and are expected to receive more attention.

In the past decade the original work by Connors [5] has given impetus to numerous studies of cylinders in cross flow. The dynamic instability of cylinders in cross flow has been confusing, but the development of various models and experimental data, in particular the semi-analytical model, has shed light on the problem. Although our understanding of the problem remains incomplete, there is a sound basis and direction for future development toward quantifying critical flow velocity.

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# NONSTATIONARY RESONANCE OSCILLATIONS

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**Abstract.** This article describes nonstationary oscillations in combination resonances, factors affecting nonstationary responses, and applications and unsolved problems of nonstationary responses.

Nonstationary resonance responses occur when external excitation parameters – frequency, amplitude, or both – vary with time close to stationary resonance frequencies. This process is also known as passage through a resonance or sweep through a resonance.

The first concerted investigations of nonstationary responses were presented in a monograph by Yu.M. Mitropol'skii [1]. Mitropol'skii, like most of the Russian School of Mechanicians, limited his analysis of nonstationary responses to dynamic and parametric resonances. A more extensive treatment of this phenomenon can be found in the book by R.M. Evan-Iwanowski [2]. He presents nonstationary responses for combination resonances – additive (summation) and differential.

A stationary combination resonance is characterized by the following relationship between the frequency  $\nu$  of the external harmonic excitation and the natural frequencies  $\omega_j$ ,  $j = 1, 2, \dots, n$  of the system:

$$k_0 \nu = \sum_{j=1}^n K_j \omega_j \quad (1)$$

where  $k_0$  and  $k_j$  are integers – positive, negative, or zero – and  $n$  is the number of degrees of freedom of the system. The phenomenon that occurs when  $k_0 = 0$  is called internal resonance. When all  $k_j$  are positive, an additive (summation) resonance occurs. If some  $k_j$  are negative, the result is differential resonance [3]. Nonstationary responses occur when the external excitation  $P(t) = H(t) \cos \theta(t)$ ; that is, when the frequency of excitation  $\nu(t) = \dot{\theta}(t)$ , the

amplitude of excitation  $H = H(t)$ , or both  $\nu$  and  $H$  are functions of time.

It has been found that either linear or cyclic variations of these parameters with time are sufficient to describe nonstationary responses. More complicated time functions of the transitions do not provide any essentially new information.

## NONSTATIONARY OSCILLATIONS IN COMBINATION RESONANCES

Salient features of nonstationary responses of systems exhibiting either parametric\*\*\* or combination additive resonances can be described from the behavior of a cylindrical panel subjected to axial and transverse periodic loads (Figure 1) and simply supported along all edges and sides. Consider linear variation of the frequency  $\nu_1(t) = \nu_0 + \alpha t$  [4];  $\nu_0$  and  $\alpha$  are constants.

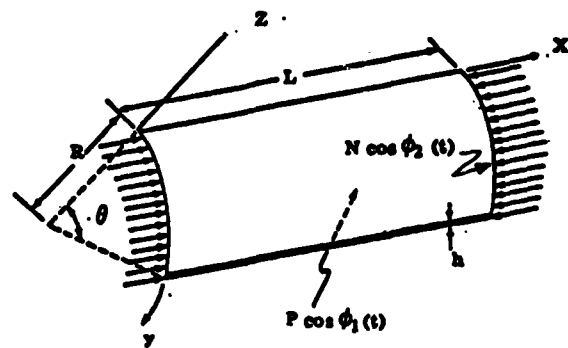


Figure 1. Cylindrical Panel and Loading

$$\nu_1(t) = \phi_1(t) = \nu_0 + \alpha t$$

Figure 2 is a summary of nonstationary responses. Three categories of the response – denoted by C1,

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\*\*\*The parametric (main) resonance is, in essence, an additive combination resonance whereby two distinct frequencies coalesce into a double frequency.

C2, and C3 in Figure 2 -- can be distinguished, depending on the rate of transition  $\alpha$ . Responses in the category C1 follow the stationary response, where  $\nu_0$  is assumed to be constant. In C2 the response tends to the initial condition. In C3 the response tends to static equilibrium, sometimes dropping rapidly to the equilibrium condition.

Detailed analysis of nonstationary responses leads to a startling situation. The separation between the categories C1, C2, and C3 is very sharp. For instance the small difference in the transition (sweep) rates between  $\alpha = 1.269$  and  $\alpha = 1.268$  -- i.e., only 0.001 -- produces a marked difference in the nonstationary response. In the first case the response tends to infinity (curve C1 of Figure 3); in the second case the response tends to a finite value (curve C2 of Figure 3). This type of behavior has been observed for other systems with various additive resonances [2].

Another somewhat puzzling manifestation of nonstationary responses is shown in Figure 4 (and to some extent in Figure 3). For the first four or five cycles the response C1 ( $\alpha = 0.06$ ) and C2 ( $\alpha = 0.04$ ) almost coincide. Later, however, they diverge dramatically. An explanation for such behavior is still being sought by the authors. The answer evidently

lies in the ranges of values of  $\alpha$  and possibly other factors. The initial conditions or variations of the material constants do not provide any clue.

A remark pertaining to the analysis of systems excited by external forces with randomly varying frequencies (i.e., with randomly varying  $\alpha$ ) is appropriate. From the preceding paragraph, it can be concluded that only statistical analyses can be carried out for some definite ranges of  $\alpha$ . Otherwise, it is difficult to imagine how responses can jump from relatively small values (curves C2 and C3 for some  $\alpha$ ) to the excessively large values (curves C1 for other  $\alpha$ ).

Laboratory experiments conducted for a discrete system consisting of three masses (three degrees of freedom) and exhibiting an additive combination resonance (among other resonances)  $\nu = \omega_1 + \omega_2 + \omega_3$  support analytical results [5]. Stationary and nonstationary responses for this experiment are shown in Figures 5 and 6 ( $\omega_1$ ,  $\omega_2$ , and  $\omega_3$  are the natural frequencies of the system). Figure 6 shows experimental results for the decreasing excitation frequencies,  $\nu(t) = \nu_0 - \alpha t$ . For such cases, the amplitudes of the nonstationary responses are decreasing [5].

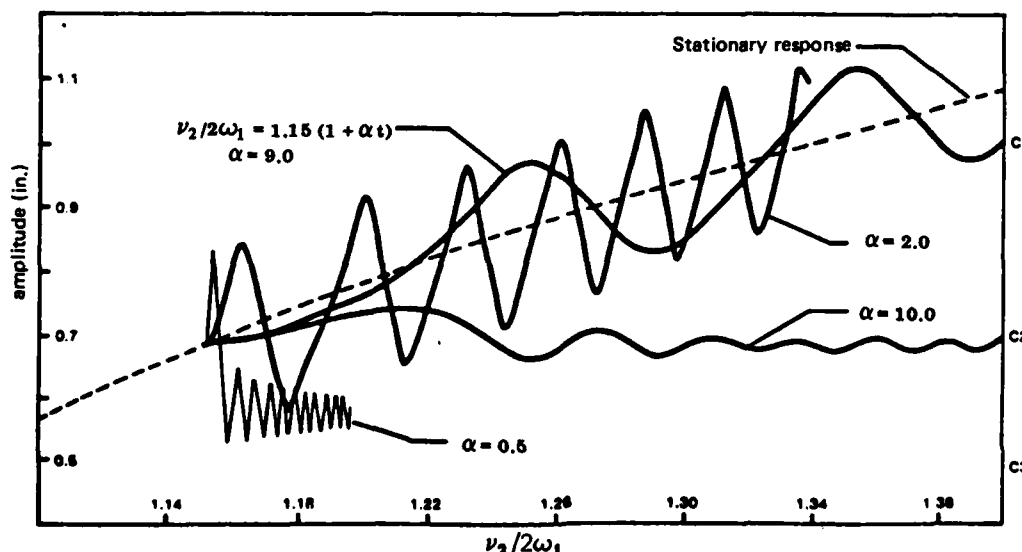


Figure 2. Transition through Resonance: Effect of Sweep Rates on Resonance Response

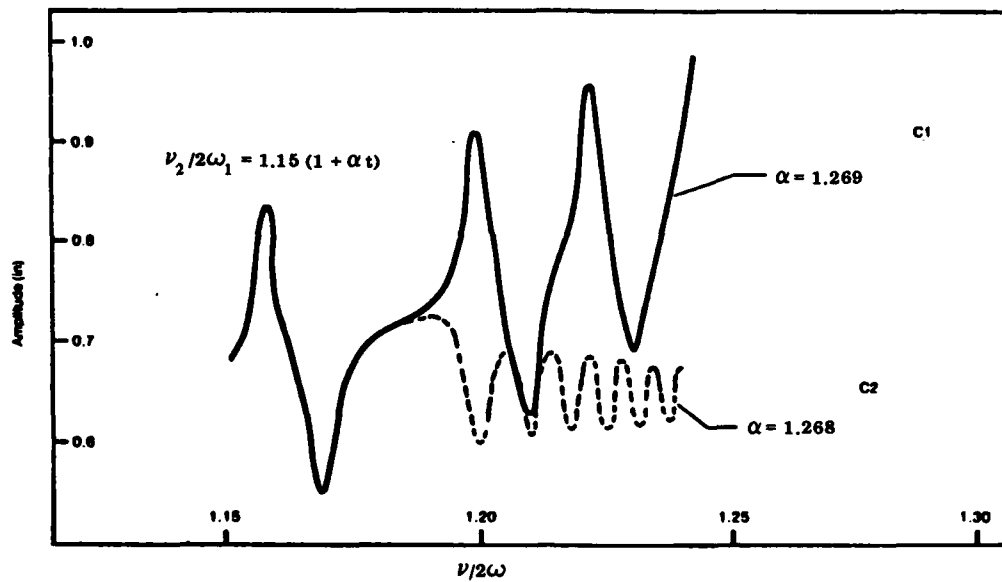


Figure 3. Transition through Resonance: Response Category Changes for Very Close Sweep Rate

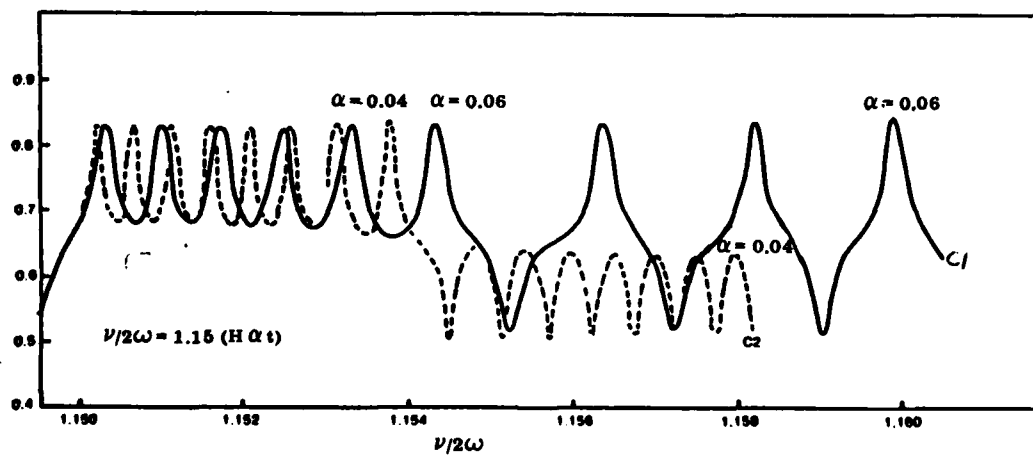


Figure 4. ( $\omega = \nu/2$ ) Parametric Resonance: Nonstationary Response

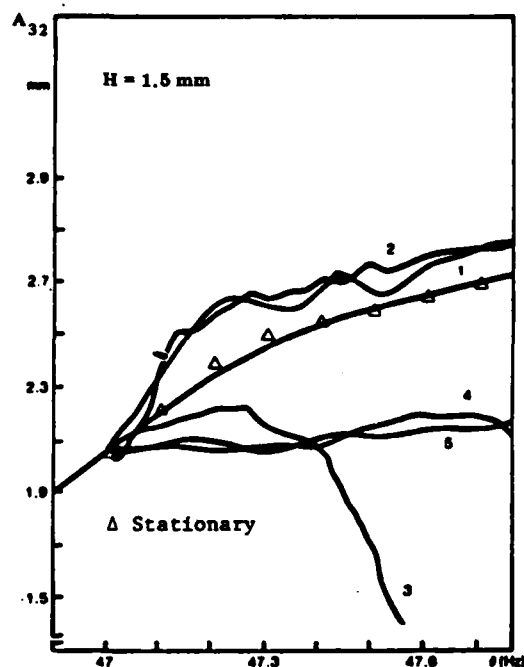


Figure 5.  $\nu = \omega_1 + \omega_2 + \omega_3$ . Combination Resonance  
(See Table.  $\nu = \nu_0 + \alpha t$ )

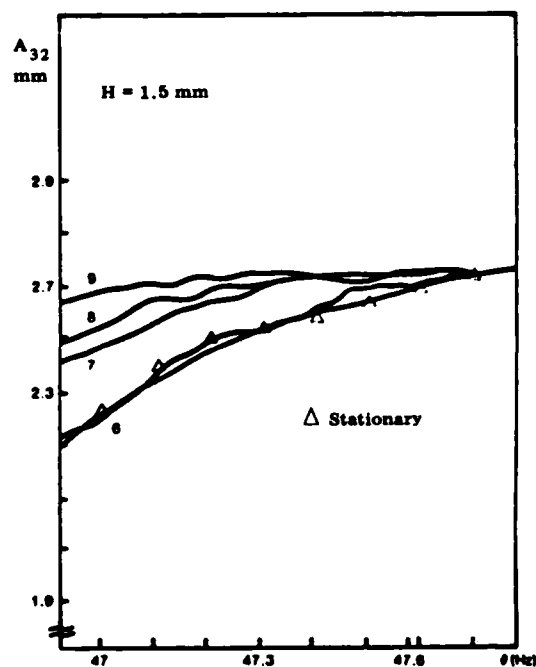


Figure 6.  $\nu = \omega_1 + \omega_2 + \omega_3$ . Combination Resonance  
(See Table.  $\nu = \nu_0 + \alpha t$ )

Table. Parameter Specifications  
 $\nu = \omega_1 + \omega_2 + \omega_3$

Case	$\nu_0$	$\alpha$	$H_{mm}$
1	47.6	0.025	1.5
2	47.6	0.075	1.5
3	47.6	0.25	1.5
4	47.6	0.75	1.5
5	47.6	2.5	1.5
6	48.4	-0.075	1.5
7	48.4	-0.75	1.5
8	48.4	-1.0	1.5
9	48.4	-2.5	1.5

Similar manifestations of nonstationary responses have been observed for gyroscopic systems [3] and systems subjected to nonconservative pulsating forces – follower forces, for instance [6]. The nonstationary response of the gyroscopic system shown in Figure 7 exhibits the same characteristic as the panel in Figure 2.

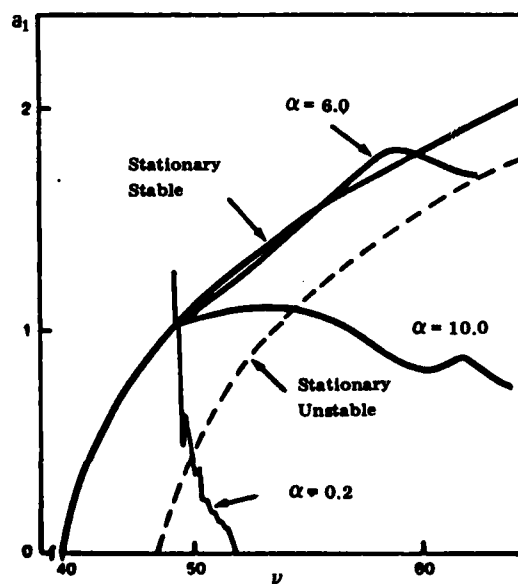


Figure 7.  $\nu = \omega_1 - \omega_2$ . Combination Resonance  
( $\nu_0 = 49$  for all curves)

Figure 8 shows nonstationary amplitudes of the system for cyclic variation of the excitation frequency for  $\nu = 60 + 2.5 \sin 0.5t$  (curve a) and  $\nu = 60 + 2.5 \sin t$  (curve b). Note again that these two responses are drastically different; they apparently depend on the frequency of the transition (sweep). One exhibits cyclic variation of the amplitude, and another tends rapidly to zero.

Interesting and puzzling results have been obtained for variations of the amplitude  $H(t)$  of the forcing function  $P(t) = H(t) \cos \theta(t)$ ;  $\nu(t) = \dot{\theta}(t)$ , and  $\nu$  is kept constant in Figure 9. Simultaneous variations of both  $H(t)$  and  $\nu(t)$  [2] are shown in Figure 10. Figure 9 shows the nonstationary amplitude for  $H(t) = H_0 + \alpha_1 t$ ,  $\nu = \text{constant}$  for various values of  $\alpha_1$ . Figure 10 presents the results for  $H(t) = H_0 + \alpha_1 t$  and  $\nu = \nu_0 + \alpha t$  for various values of  $\alpha_1$  and  $\alpha$ . Additional background on the subject is available [9-32].

### FACTORS AFFECTING NONSTATIONARY RESPONSES

The factors that markedly effect nonstationary responses are, in order of significance [2]:

- geometrical nonlinearities: large deformations and attendant longitudinal and rotatory inertias
- nonlinear restoring and dissipative forces, particularly, hysteretic dissipative forces, which can considerably modify the response
- nonideal external excitations\* resulting in the interaction between excitation and system responses

### PRACTICAL APPLICATIONS

In some complex systems in which the mechanical strength of the system is low, resonance frequencies can be found experimentally by sweeping the excitation frequency rapidly through the wide range, thus avoiding a high buildup of resonance amplitudes. Particularly convenient is a variation in the direction of decreasing frequencies by which the amplitudes are rapidly decreasing. Another possible practical application of nonstationary responses is effective stabilization of resonance oscillations by an appropriate transition rate through the resonance (see Figure 8).

\*Referred to as sources with limited power [20].

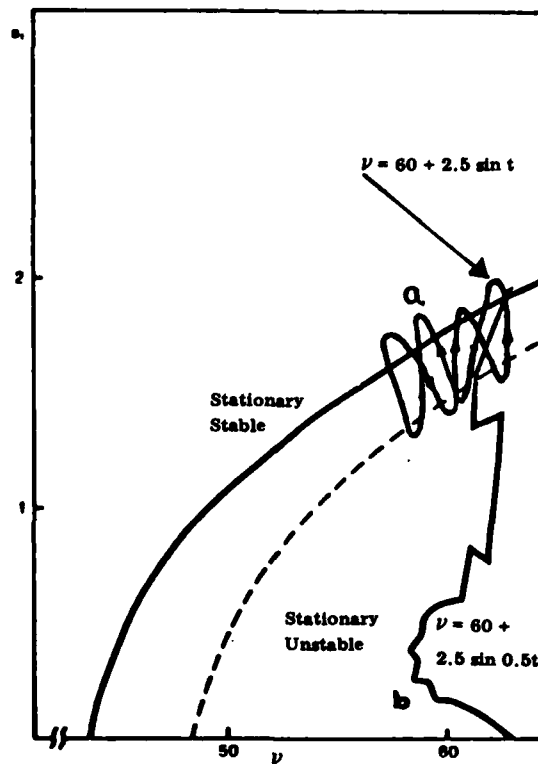


Figure 8.  $\nu = \omega_1 - \omega_2$ . Combination Resonance

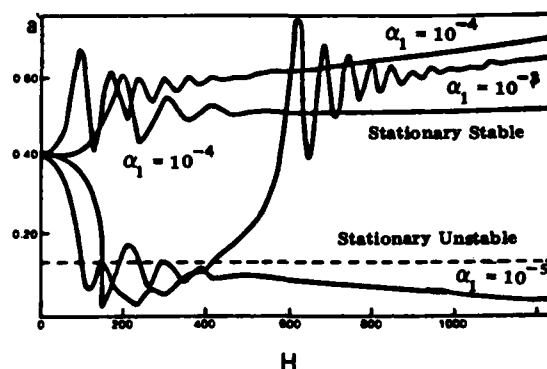


Figure 9. Nonstationary Amplitude  
( $H = H_0 + \alpha_1 t$ )

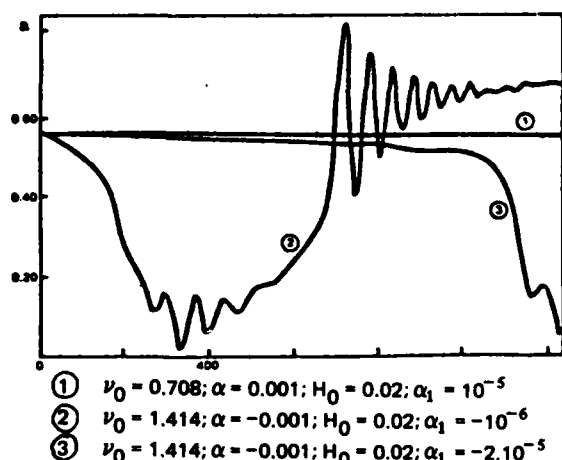


Figure 10. Nonstationary Amplitude

### UNSOLVED PROBLEMS

It is essential to determine the parameters of system excitation and initial conditions that are responsible for a specific category of nonstationary responses; i.e., (i) tending to infinity, (ii) tending to initial conditions, or (iii) dropping to static equilibrium. This can be significant for the cyclic variation of the frequency  $\nu(t)$ . In this case very small perturbations can totally (zero amplitude) stabilize the system (see Figure 8). Another problem is the interaction of various modes. It is significant that some very distant modes without much energy individually can transfer this energy to one mode and cause failure.

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# BOOK REVIEWS

## ACOUSTICS: AN INTRODUCTION TO ITS PHYSICAL PRINCIPLES AND APPLICATIONS

A.D. Pierce  
McGraw-Hill Book Co., New York, NY  
1981, 642 pp, \$29.95

This book is one of a series of texts in mechanical engineering and will be a highly useful reference in acoustics. It is a carefully written, intermediate-level survey of the physics underlying several areas of acoustics and contains an extensive bibliography and measurement standards. The book can be used as a guide to the more advanced literature.

The scope is much broader than that in Theoretical Acoustics by Morse and Ingard. Included are such topics as the effects of moving media, not usually found in textbooks, and the following chapters:

1. The Wave Theory of Sound
2. Quantitative Measures of Sound
3. Reflection, Transmission, and Excitation of Plane Waves
4. Radiation from Vibrating Bodies
5. Radiation from Sources near and on Solid Surfaces
6. Room Acoustics
7. Low Frequency Models of Sound Transmission
8. Ray Acoustics
9. Scattering and Diffraction
10. Effects of Viscosity and Other Dissipative Processes
11. Nonlinear Effects in Sound Propagation

It is somewhat surprising that a chapter was not included on acoustic measurements, even though the author stated that some topics . . . such as jet noise and acoustic imaging . . . were purposely omitted so that the text will not be unmanageable in length.

An extensive subject index as well as a name index are included. The text would be more useful, however, if additional example problems had been included. Another suggested improvement is the inclusion of answers to the exercises at the end of the chapters. Overall, this book will be a welcome addition to the library of the graduate level engineer with an interest in acoustics.

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## NOISE CONTROL SOLUTIONS FOR THE WOOD PRODUCTS INDUSTRY

R.K. Miller, W.F. Montone, and M.D. Oviatt  
Fairmont Press, Atlanta, GA  
1980, 72 pp

This book is a collection of noise control concepts designed for different types of machinery used in the wood products industry. It contains a brief summary of some existing literature on the subject. The book opens with a discussion on OSHA and an approach to industrial noise control. Each chapter contains tables and figures that provide some information about noise control. Unfortunately, this book is not as good as other textbooks that present excellent treatments of noise control and are not necessarily tailored specifically to the wood products industry.

The proposed solutions are aimed at satisfying OSHA requirements and typically involve using enclosures to attain a desired noise level; however, the only enclosures mentioned are made of wood, which may not be allowed in production environments. Spectra are shown for various types of wood products equipment, but no discussion on how these spectra can be used is presented. Several other important details are missing: no index; no discussion of community im-

part of specific equipment operation or prediction and measurement of equipment noise.

The authors did not succeed in achieving the objectives stated at the beginning of the book. It could be used as a primer, but the more experienced reader can obtain better information on noise problems in the wood products industry from other books on noise control.

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## MECHANICS TODAY, VOLUME 6

S. Nemat-Nasser, Editor  
Pergamon Press, New York, NY  
1981, 204 pp, \$50.00

This is the sixth volume of a series containing research level state-of-the-art review articles on various topics in theoretical and applied mechanics. The book contains three major articles and an addendum to a previously published article in another volume of the series.

In the first article McCoy treats elastic solids with a microstructure much larger than the atomic scale but much smaller than the characteristic size of the entire structure. Examples include polycrystalline solids and fiber-reinforced composites in which each randomly oriented crystal, fiber, or matrix region can be treated as a linearly elastic solid. Statistical models are used to relate microstructural properties to the elastic characteristics of the entire structure.

In the second article Sewell presents an extensive tutorial article on the subject of catastrophe theory. This subject is acquiring a great importance in mechanics; readers who want a simpler exposition of the subject should read a reference that was published in the *International Journal of Mechanical Engineering Education* and is the work of the same author.

Increased interest in qualitative methods in non-linear mechanics makes reasonable the current interest in catastrophe theory by analytically inclined

engineering scientists. Those interested in the connection between the theory and more traditional approaches to the same problem area are directed to to the review article "Vibrations and Stability of Mechanical Systems II" by K. Huseyin in the *Shock and Vibration Digest* (13 (1), Jan 1981, pp 21-29).

In the third article Zarka and Casier analyze the cyclic loading of several simple elastic-plastic structures. Three parallel bars in axial loading, a thin tube, and a rectangular plate are analyzed when subjected to a prescribed traction or when the temperature varies as a sine curve. The responses of these structures are analyzed to answer such questions as does the deformation reach a periodic state, and, if not, how does the response of the structure proceed toward failure?

The authors propose an extension of their analyses to general structures. They begin with their results, which are necessarily restricted to simple structures. The generalization is achieved by obtaining bounds in parameter space.

The addendum by F. Erdogan presents recent results obtained by the author and updates material presented in Vol. 4 of *Mechanics Today*, 1978; pp 1-86, under the title "Mixed Boundary-Value Problems in Mechanics." The same title is retained in the addendum.

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## THE CALCULUS OF VARIATIONS AND OPTIMAL CONTROL: AN INTRODUCTION

G. Leitmann  
Vol. 24 of *Mathematical Concepts in Science and Engineering*  
Plenum Press, New York, NY  
1981, 311 pp, \$35.00

This volume combines two related topics, each of which deserves extensive treatment in its own right.

However, in combining the two, the author is able to show the smooth transition from the calculus of variations to that of optimal control. The transition highlights the common features of both subjects and thus shows the continuity between the classical subject of variational calculus and a major area of its application in modern engineering, optimal control.

Part I, on the calculus of variations, is much shorter than the second part, and seems intended as a review of the subject in order to show that optimal control is a natural extension. It is confined to the simplest problem -- with fixed end points. The necessary conditions of Euler, Weierstrass, and Jacobi are developed as are the corner conditions for problems with discontinuous slopes. Topics that belong to the calculus of variations in the classical framework, such as free end points and transversality conditions, are deferred to the second part and are treated within the context of optimal control.

The chapter on the inverse problem of variational calculus is sketchy and does not include some of the more interesting and direct approaches that have become recently available. The inverse technique is used to develop conservation laws in a simpler manner than the usual set-theoretic methods. These results are also useful in stability considerations and thus should have been included in this chapter.

Part II treats optimal control in detail. Chapter 10 covers the preliminary material; the maximum

principle is obtained in Chapter 11 by an elegant method. In Chapter 12 two important applications are given: time optimality of a constant-power rocket and navigation. Chapter 13 generalizes some of the work not included in Chapter 11. Later chapters deal with such topics as singular systems, the maximum range of rockets, and bang-bang controls that are time optimal. Nonstandard material in the final chapters ranges from problems in botany and economics to a taste-optimal decision in choosing the best Camembert cheese!

The reviewer believes that the highly mathematical choice of notation will decrease the number of engineers and applied scientists who could most benefit from the text. After all, a great deal of this material has been available in the literature before and has been presented in the standard notation of ordinary calculus. The author of the text, who teaches in an engineering department, appears to have written his book more for an audience composed of mathematicians than one consisting of engineers and applied scientists.

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# SHORT COURSES

## AUGUST

### DESIGN AND ANALYSIS OF ENGINEERING EXPERIMENTS

Dates: August 1-12, 1983

Place: Ann Arbor, Michigan

Objective: Recent developments in the field of testing, methods for designing experiments, interpretation of test data, and procedures for better utilization of existing data. Design of experiments with small numbers of test pieces and runs with high dispersion are emphasized. Obtaining maximum information from limited data is stressed.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, The University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

### SIMULATION USING GPSS

Dates: August 8-12, 1983

Place: Ann Arbor, Michigan

Objective: This course is designed for persons working in management science, operations research or analysis, facilities planning, or manufacturing system design. Simulation concepts are illustrated with GPSS applications, using case studies. Computer workshops provide participants with hands-on experience in building and using GPSS models.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, The University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

### MACHINERY VIBRATION ANALYSIS

Dates: August 16-19, 1983

Place: New Orleans, Louisiana

Dates: November 15-18, 1983

Place: Chicago, Illinois

Objective: In this four-day course on practical machinery vibration analysis, savings in production

losses and equipment costs through vibration analysis and correction will be stressed. Techniques will be reviewed along with examples and case histories to illustrate their use. Demonstrations of measurement and analysis equipment will be conducted during the course. The course will include lectures on test equipment selection and use, vibration measurement and analysis including the latest information on spectral analysis, balancing, alignment, isolation, and damping. Plant predictive maintenance programs, monitoring equipment and programs, and equipment evaluation are topics included. Specific components and equipment covered in the lectures include gears, bearings (fluid film and antifriction), shafts, couplings, motors, turbines, engines, pumps, compressors, fluid drives, gearboxes, and slow-speed paper rolls.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

### DYNAMIC BALANCING

Dates: August 17-18, 1983

September 21-22, 1983

October 19-20, 1983

November 16-17, 1983

Place: Columbus, Ohio

Objective: Balancing experts will contribute a series of lectures on field balancing and balancing machines. Subjects include: field balancing methods; single, two and multi-plane balancing techniques; balancing tolerances and correction methods. The latest in-place balancing techniques will be demonstrated and use in the workshops. Balancing machines equipped with microprocessor instrumentation will also be demonstrated in the workshop sessions. Each student will be involved in hands-on problem-solving using the various balancing techniques.

Contact: R.E. Ellis, IRD Mechanalysis, Inc., 6150 Huntley Road, Columbus, OH 43229 - (614) 885-5376.

## **VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION**

Dates: August 22-26, 1983

Place: Santa Barbara, California

Dates: October 17-21, 1983

Place: England

Dates: October 24-28, 1983

Place: Boulder, Colorado

Dates: November 21-25, 1983

Place: Ottawa, Ontario

Dates: November 28 - December 3, 1983

Place: Cincinnati, Ohio

Dates: December 5-9, 1983

Place: Santa Barbara, California

Objective: Topics to be covered are resonance and fragility phenomena, and environmental vibration and shock measurement and analysis; also vibration and shock environmental testing to prove survivability. This course will concentrate upon equipments and techniques, rather than upon mathematics and theory.

Contact: Wayne Tustin, 22 East Los Olivos Street, Santa Barbara, CA 93105 - (805) 682-7171.

## **DYNAMICS AND CONTROL OF LARGE FLEX- IBLE STRUCTURES**

Dates: August 22-26, 1983

Place: Los Angeles, California

Objective: The theme of the course is the need to integrate the understanding of physical system dynamics with the methods of modern control theory to accomplish the practical control of the class of large, flexible structures of current interest. Attention focuses initially on the idealization of spacecraft structures and the formulation of their equations of motion. Dynamics and control theory are then developed in integrated teams, with emphasis gradually shifting to the applications of modern control theory. The limitations of conventional optimal estimation and control theory for such applications are illustrated, and various techniques for reducing the sensitivity of conventional methods to modeling errors are presented.

Contact: Short Course Program Office, UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024 - (213) 825-1295 or 825-3344.

## **SEPTEMBER**

### **12TH ADVANCED NOISE AND VIBRATION COURSE**

Dates: September 19-23, 1983

Place: Southampton, England

Objective: The course is aimed at researchers and development engineers in industry and research establishments, and people in other spheres who are associated with noise and vibration problems. The course, which is designed to refresh and cover the latest theories and techniques, initially deals with fundamentals and common ground and then offers a choice of specialist topics. There are over thirty lectures, including the basic subjects of acoustics, random processes, vibration theory, subjective response and aerodynamic noise, which form the central core of the course. In addition, several specialist applied topics are offered, including aircraft noise, road traffic noise, industrial machinery noise, diesel engine noise, process plant noise, environmental noise and planning and laser techniques for non-contact measurements.

Contact: Mrs. Maureen Strickland, ISVR Conference Secretary, The University, Southampton SO9 5NH, England - (0703) 559122 ext. 2310/532.

### **MODAL TESTING COURSE**

Dates: September 20-22, 1983

Place: Washington, D.C.

Objective: Vibration testing and analysis associated with machines and structures will be discussed in detail. Practical examples will be given to illustrate important concepts. Theory and test philosophy of modal techniques, methods for mobility measurements, methods for analyzing mobility data, mathematical modeling from mobility data, and applications of modal test results will be presented.

Contact: Dr. Ronald L. Eshleman, Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

### **STRUCTURAL DYNAMICS: COMPUTER-ORIENT- ED APPROACH WITH APPLICATIONS**

Dates: September 26-30, 1983

Place: Los Angeles, California

Objective: The course emphasizes discrete methods, numerical methods, and structural modeling for computer-oriented solution of various structural dynamic problems. Some recent developments in the structural dynamic analysis of parametrically excited systems, rotating systems, and systems in which fluid-structure dynamic interactions occur are also considered.

Contact: Short Course Program Office, UCLA Extension, P.O. Box 24901, Los Angeles, CA 90024 - (213) 825-1295 or 825-3344.

## OCTOBER

### UNDERWATER ACOUSTICS AND SIGNAL PROCESSING

Dates: October 3-7, 1983

Place: State College, Pennsylvania

Objective: This course is designed to provide a broad, comprehensive introduction to important topics in underwater acoustics and signal processing. The primary goal is to give participants a practical understanding of fundamental concepts, along with an appreciation of current research and development activities. Included among the topics offered in this course are: an introduction to acoustics and sonar concepts, transducers and arrays, and turbulent and cavitation noise; an extensive overview of sound propagation modeling and measurement techniques; a physical description of the environment factors affecting deep and shallow water acoustics; a practical guide to sonar electronics; and a tutorial review of analog and digital signal processing techniques and active echo location developments.

Contact: Alan D. Stuart, Course Chairman, Applied Research Laboratory, The Pennsylvania State University, P.O. Box 30, State College, PA 16801 - (814) 865-7505.

# ABSTRACTS FROM THE CURRENT LITERATURE

Copies of publications abstracted are not available from SVIC or the Vibration Institute, except those generated by either organization. Government Reports (AD-, PB-, or N-numbers) can be obtained from NTIS, Springfield, Virginia 22151; Dissertations (DA-) from University Microfilms, 313 N. Fir St., Ann Arbor, Michigan 48106; U.S. Patents from the Commissioner of Patents, Washington, DC 20231; Chinese publications (CSTA-) in Chinese or English translation from International Information Service Ltd., P.O. Box 24683, ABD Post Office, Hong Kong. In all cases the appropriate code number should be cited. All other inquiries should be directed to libraries. The address of only the first author is listed in the citation. The list of periodicals scanned is published in issues 1, 6, and 12.

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# MECHANICAL SYSTEMS

## ROTATING MACHINES

(Also see No. 1494)

83-1279

**Critical Speeds of Unbalanced Rotors Caused by Torque Fluctuation, Bearing Anisotropy and Dead Weight (Biegekritische Drehzahlen unwuchtiger Rotoren infolge Drehmomentschwankungen, Lageranisotropie und Eigengewicht)**

H. Martins and K. Teschner

Fachhochschule Hamburg, Fed. Rep. Germany, Konstruktion, 35 (1), pp 3-10 (Jan 1983) 7 figs, 5 refs

(In German)

**Key Words:** Rotors, Critical speed

In the article, both critical and sub-critical speeds are calculated for Laval rotors. The subcriticals, obtained by a non-linear calculation, are defined only by rotor parameters and occur at whole number intervals of the flexural natural frequency of the rotor. The combination criticals are a combination of flexural natural frequency of the rotor and the torsional frequency. They occur above, as well as, below the normal critical speeds, and should be watched; e.g., in cases where electric machines are coupled to reciprocating engines.

83-1280

**Energetic Evaluation of Stability in Rotor-Bearing System (Contribution of Each Element to Logarithmic Decrement)**

M. Kurohashi, T. Iwatsubo, R. Kawai, and T. Fuji-kawa

Mech. Engrg. Res. Lab., Kobe Steel, Ltd., 1-Chome, Wakinohama-Cho, Chuo-Ku, Kobe, Japan, Bull. JSME, 26 (212) pp 276-282 (Feb 1983) 11 figs, 7 tables, 9 refs

**Key Words:** Rotors, Fluid-induced excitation, Stability

A calculation method for the contribution of each element (bearing, etc.) to the logarithmic decrement in a rotor-bearing

system is shown based on the relation between the dissipative energy and the logarithmic decrement. By applying the method to a rotor-bearing system which is subjected to a fluid dynamic destabilizing force, the stability of the system is evaluated. The effects of the axial location of disk, the stiffness of rotor and the anisotropy of bearing characteristics on the stability of the system are described and the contribution of each element to the stability is discussed.

83-1281

**Unbalance Response of a Single Mass Rotor on Fluid Film Bearings Using Modal Analysis**

R.B. Bhat

Dept. of Mech. Engrg., Concordia Univ., Montreal, Quebec, Canada, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 649-655, 9 figs, 1 table, 11 refs

**Key Words:** Modal analysis, Rotors, Unbalanced mass response, Critical speeds

Critical speeds and unbalance response in synchronous whirl of a single mass rotor, supported on hydrodynamic bearings are studied, employing modal analysis. Due to the asymmetry in the cross coupled coefficients in a fluid film bearing, a conventional normal mode analysis is not possible and it is necessary to take into account the adjoint system in the analysis. The orthogonality relation between the modes of the original system and those of the adjoint system is used to uncouple the system of equations of motion. A discussion of the application of modal analysis to study the dynamics of rotors is included.

83-1282

**Rotor Dynamic Simulation and System Identification Methods for Application to Vacuum Whirl Data**

A. Berman, N. Giansante, and W.G. Flannelly  
Kaman Aerospace Corp., Bloomfield, CT, Rept. No. R-1496, NASA-CR-159356, 188 pp (Sept 30, 1980) N83-11117

**Key Words:** Rotors, System identification techniques, Natural frequencies, Mode shapes

Methods of using rotor vacuum whirl data to improve the ability to model helicopter rotors were developed. The work consisted of the formulation of the equations of motion of elastic blades on a hub using a Galerkin method; the develop-

ment of a general computer program for simulation of these equations; the study and implementation of a procedure for determining physical parameters based on measured data; and the application of a method for computing the normal modes and natural frequencies based on test data.

**83-1283**

**Torsional Oscillations in Constant-Velocity Drives Incorporating Two Cardan Joints: the Present State of Knowledge and the Design of an Experimental Research**

A. Costa

Dept. of Mech. Engrg., Politecnico di Milano, Italy, *Meccanica*, 17 (4), pp 179-200 (Dec 1982) 12 figs, 4 tables, 24 refs

**Key Words:** Shafts, Drive shafts, Cardan shafts, Torsional vibration

The paper reports a survey and a comparison between theoretical predictions (as well as a few experimental findings already known) on dynamic stability of torsional oscillations in two-Cardan-joint constant-velocity drives. The design of a special test apparatus is described which can be used in a broad range of testing conditions and can measure and record the oscillatory relative motion of the drive output shaft.

**83-1284**

**A Nonlinear Method for Predicting Unsteady Sheet Cavitation on Marine Propellers**

F. Stern and W.S. Vorus

Science Applications, Inc., Ship Hydrodynamics Div., Annapolis, MD, *J. Ship Res.*, 27 (1), pp 56-74 (Mar 1983) 14 figs, 2 tables, 17 refs

**Key Words:** Propellers, Marine propellers, Cavitation

A method is presented which provides a basis for predicting the nonlinear dynamic behavior of unsteady propeller sheet cavitation. The method separates the fluid velocity potential boundary-value problem into two parts, static and dynamic, which are solved sequentially in a forward time stepping procedure. The static potential problem is for the cavity fixed instantaneously relative to the propeller and the propeller translating through the nonuniform wake field. This problem can be solved by standard methods. The dynamic potential represents the instantaneous reaction of the cavity to the static potential field and thus predicts the cavity's deformation and motion relative to the blade. A solution is

obtained for the dynamic potential by using the concepts of slender-body theory to define near- and far-field potentials which are matched to form the complete solution.

## METAL WORKING AND FORMING

(See Nos. 1452, 1487)

# STRUCTURAL SYSTEMS

## BRIDGES

**83-1285**

**Multimode Bridge Response to Wind Excitations**

Y.K. Lin and J.N. Yang

Univ. of Illinois, Urbana, IL 61801, *ASCE J. Engrg. Mech.*, 109 (2), pp 586-603 (Apr 1983) 1 fig, 1 table, 18 refs

**Key Words:** Bridges, Random vibration, Wind-induced excitation

Spectral analysis of random vibration is used to develop a new multimode linear theory for the computation of cross-spectra of bridge response to turbulent wind excitations. New interpretations are given to previous works in the literature, and the results compared. The comparison enables a direct utilization of previously obtained experimental results, as well as clarification of the implication and limitation of previously proposed simplified procedures.

## BUILDINGS

(Also see No. 1384)

**83-1286**

**Seismic Safety: 10-Story UBC Designed Steel Building**

Shih-Sheng Paul Lai

National Taiwan Inst. of Tech., Taipei, Taiwan, *R.O.C., ASCE J. Engrg. Mech.*, 109 (2), pp 557-575 (Apr 1983) 16 figs, 4 tables, 28 refs

**Key Words:** Buildings, Steel, Multistory buildings, Seismic response

In evaluating the seismic safety of a 10-story Uniform Building Code-designed steel moment-resisting building, three major sources of uncertainty have been extensively examined: the representation of earthquake environment; the structural dynamic properties; and the method of structural analysis. By combining these uncertainties, the reliability of local inelastic response conditional on the peak ground acceleration is assessed for the frame. The overall seismic safety is investigated by introducing the site-specific seismic risk.

### 83-1287

#### **Vibration of Asymmetrical Building-Foundation Systems**

T. Balendra, Chan Went Tat, and Seng-Lip Lee  
Dept. of Civil Engrg., Natl. Univ. of Singapore, Singapore, ASCE J. Engrg. Mech., 109 (2), pp 430-449 (Apr 1983) 6 figs, 2 tables, 23 refs

**Key Words:** Buildings, Interaction: soil-structure, Interaction: structure-foundation

The vibrational effect caused by an earthquake on an asymmetrical building foundation system is determined by reducing the governing equations of motion to a set of coupled integro-differential equations involving only the interaction displacements, with the degrees of freedom of the superstructure being eliminated by the modal analysis technique. The formulation facilitates to discard the insignificant modes of the superstructure and, as such, the effort involved in the solution of the eigenvalue problem required for the modal analysis is minimal, especially for a particular class of torsionally coupled buildings. The influence of the eccentricity, shear wave velocity, and the direction of earthquake on the dynamic response of the system is investigated.

### 83-1288

#### **A Versatile Finite Strip Model for Three-Dimensional Tall Building Analysis**

W. Kanok-Nukulchai, S.-Y. Lee, and P. Karasudhi  
Div. of Struc. Engrg. and Construction, Asian Inst. of Tech., Bangkok, Thailand, Intl. J. Earthquake Engrg. Struc. Dynam., 11 (2), pp 149-166 (Mar/Apr 1983) 14 figs, 6 tables, 12 refs

**Key Words:** Buildings, Finite strip method

This study endeavors to show the inadequacy of thin beam eigenfunctions commonly used to represent displacement

profiles of tall buildings in the finite strip analysis. Particularly, the model fails to reflect the correct building behavior whenever the story-shear distortion may be significant. An attempt is made, therefore, to develop a new set of strip shape functions that is free of the above shortcoming. A polynomial series is specially constructed and shown to be effective for all building types. Several tall building examples are tested and the results clearly exhibit the versatility and surprisingly high accuracy of the proposed finite strip model, in both static and free vibration analyses.

### 83-1289

#### **Comparative Seismic Analyses of a Framed Tube with Localized and General Non-Linearity**

A.A. Huckelbridge, Jr. and R.M. Ferencz  
Dept. of Civil Engrg., Case Western Reserve Univ., Cleveland, OH, Intl. J. Earthquake Engrg. Struc. Dynam., 11 (2), pp 167-177 (Mar/Apr 1983) 11 figs, 14 refs

**Key Words:** Framed tube technique, Tubes, Buildings, Multistory buildings, Seismic analysis

The seismic response of a 30-story framed tube is examined. A description is given of an analysis procedure utilizing a linear substructure to represent the building superstructure, achieving considerable economy in computational effort. Localized nonlinearity in the form of transient foundation uplift is included as a response feature. Comparisons of substructured to non-substructured analyses for the same ground motion are made.

### 83-1290

#### **Probability of Failure from Abnormal Load**

B. Ellingwood, E.V. Leyendecker, and J.T.P. Yao  
Ctr. for Building Tech., Natl. Bureau of Standards, Washington, D.C. 20234, ASCE J. Struc. Engrg., 109 (4), pp 875-890 (Apr 1983) 8 figs, 2 tables, 18 refs

**Key Words:** Buildings, Shock resistant design, Explosions

Abnormal loads, which usually are not considered in structural design because of their low probability of occurrence, may initiate a catastrophic failure if they occur. A case study shows that the probability of structural failure due to a gas explosion in a residential compartment may exceed probabilities associated with unfavorable combinations of ordinary design loads. Therefore, specific provision in design standards to mitigate the effects of abnormal loads appear warranted.

83-1291

**Three-Dimensional Linear Dynamic Analysis of Buildings with 32-Bit Virtual-Memory Minicomputers**

M. Gattass and J.F. Abel

Department de Engenharia Civil, P.U.C., Rio de Janeiro, R.J. 22453, Brazil, Computers Struc., 17 (1), pp 97-104 (1983) 4 figs, 5 tables, 22 refs

**Key Words:** Buildings, Dynamic structural analysis, Computer-aided techniques

This paper focuses on computer-aided analysis of three-dimensional buildings with 32-bit, virtual-memory minicomputers. Various floor, inertial, geometry, stiffness, and displacement models of three-dimensional buildings are discussed with respect to implications for computational efficiency. From this discussion a model for three-dimensional buildings is selected for use with virtual-memory minicomputers. The use of symbolic manipulation, dynamic allocation of memory, and matrix storage and manipulation to achieve computational efficiency are also examined. Examples with computational statistics illustrate the ideas presented.

**FOUNDATIONS**

(Also see Nos. 1299, 1365)

83-1292

**Seismic Response Arising from Traveling Waves**

J.R. Morgan, W.J. Hall, and N.M. Newmark

Texas A&M Univ., College Station, TX, ASCE J. Struc. Engrg., 109 (4), pp 1010-1027 (Apr 1983) 8 figs, 3 tables, 19 refs

**Key Words:** Foundations, Seismic response

Over the years observations of earthquake damage suggest that structures on large foundations respond to ground motion with less intensity than do smaller structures. The limited data obtained from instruments support these observations. The theoretical investigation described constitutes an attempt to establish the feasibility of employing the *T*-averaging traveling seismic wave procedures to investigate the effects of combined lateral motion resulting from translation and rotation of a simple structure.

83-1293

**Specifications of Input Motions for Seismic Analyses of Soil-Structure Systems within a Nonlinear Analyses Framework. Final Report**

Y. Moriwaki, R. Pyke, M. Bastick, and T. Uda  
Civil Systems, Inc., San Leandro, CA, Rept. No. EPRI-NP-2097, 140 pp (Oct 1981)  
DE82901317

**Key Words:** Interaction: soil-structure, Seismic analysis, Computer programs

A brief assessment of some rational approaches to specifying input motions within a nonlinear analysis framework is presented. Using a modified STEALTH 1D seismic and SHAKE computer codes, some points discussed in the assessment are illustrated.

**HARBORS AND DAMS**

(Also see No. 1489)

83-1294

**On the Possibility of Extracting Power from Resonant Harbour Oscillations**

V. Cossalter, G. Liberatore, and F. Toffolo

Istituto di Meccanica Applicata alle Macchine, Facoltà di Ingegneria, Università di Padova, Meccanica, 17 (4), pp 222-229 (Dec 1982) 8 figs, 15 refs

**Key Words:** Harbors, Water waves, Power plants (facilities)

The possibility of extracting wave power using energy-capturing devices placed inside specially shaped artificial basins, rather than with offshore free-floating installations, is examined. A particular type of basin - rectangular in shape with convergent mouth - was selected, where optimization of efficiency in wave energy exploitation is achieved by a movable back-wall allowing the resonant frequency of the harbor to be tuned to the variable frequency of incident waves. The dynamical behavior of the proposed harbor configuration is first investigated by means of a mathematical model, obtained by a combination of the finite element and boundary integral techniques. Experiments are then conducted in a large three-dimensional wave basin in order to verify the theoretical results. Both theoretical and experimental analyses confirmed the potentiality of the proposed solution for the purpose of exploiting wave power from the sea.

**POWER PLANTS**

(Also see Nos. 1294, 1386, 1388)

83-1295

**Non-Linear Rocking Response of Model Containment Structures**

D.K. Vaughan and J. Isenberg  
Weidlinger Associates, 3000 Sand Hill Rd., Bldg. 4,  
Suite 245, Menlo Park, CA 94025, Intl. J. Earth-  
quake Engrg. Struc. Dynam., 11 (2), pp 275-296  
(Mar/Apr 1983) 20 figs, 21 refs

**Key Words:** Containment structures, Nuclear power plants,  
Underground explosions, Interaction: soil-structure, Finite  
difference technique

Small (1/24- to 1/8-size) nuclear containment structures  
were subjected to ground shaking from buried explosions  
and to oscillating forces. The apparent natural frequency  
or resonant frequency of rocking varies inversely with ampli-  
tude of the shaking. An explicit finite difference model of  
soil-structure interaction induced by explosive loading is  
described. The results indicate that nonlinear rocking re-  
sponse is primarily a result of debonding-rebonding and  
compaction of soil at the soil-structure interface.

**83-1296**  
**Modal Analysis of Light Ion Beam Fusion Reactor**  
**Vessels**

R.L. Engelstad and E.G. Lovell  
Univ. of Wisconsin, Madison, WI 53706, Intl. Modal  
Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orland,  
FL. Spons. Union College, Schenectady, NY, pp 289-  
295, 18 figs, 1 table, 2 refs

**Key Words:** Nuclear reactors, Modal analysis, Blast response

Light ion beam inertial confinement fusion reaction vessels  
are subjected to intense dynamic overpressure and heat flux  
from nuclear microexplosions. The conceptual design pro-  
posed consists of a cylindrical chamber with hemispherical  
ends. The shell structure is supported by a gridwork of ribs  
and stringers. Modal static deflections and stresses for panel  
and beam components are developed in parametric form.  
The dependence of modal dynamic load factors upon the  
pulse shape of the fireball blast wave are identified. Maxi-  
mum DLF values are determined and characterized as func-  
tions of flexural frequencies for the various structural com-  
ponents. The dynamic response is determined by coupling  
the static results with the appropriate dynamic load factors.

**83-1297**  
**Modal and Seismic Response Analysis of Complex**  
**Control Panel Cabinets**  
T.P. Pastor

Combustion Engineering, Inc., Windsor, CT, Intl.  
Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982,  
Orlando, FL. Spons. Union College, Schenectady,  
NY, pp 608-613, 3 figs, 3 tables, 3 refs

**Key Words:** Modal analysis, Nuclear power plants, Seismic  
response

A method is presented to simplify the modal and seismic  
response analysis of complex control panel cabinets. The  
methodology presented here is valid for other types of  
cabinet assemblies that must be seismically analyzed. Also  
included is a discussion of the modeling techniques used,  
with emphasis on the key modeling assumptions made.

**83-1298**  
**Dynamic Testing and Analysis of Magnetic Fusion**  
**Containment Vessel Structure**

H.J. Weaver  
Lawrence Livermore Natl. Lab., Livermore, CA  
94550, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-  
10, 1982, Orlando, FL. Spons. Union College, Schen-  
ectady, NY, pp 579-585, 10 figs, 2 refs

**Key Words:** Nuclear reactors, Containment structures, Modal  
tests, Modal analysis, Seismic design

Dynamic (modal) testing was performed on the Magnetic  
Fusion Test Facility (MFTF) containment vessel. The seismic  
design of this vessel was heavily dependent upon the value of  
structural damping used in the analysis. The report presents  
a description of the test procedure used. It also presents an  
interpretation of the damping mechanisms observed (material  
and geometric) based upon the spatial characteristics of the  
modal parameters (mode shapes).

**83-1299**  
**Soil-Structure Interaction Analysis of a 5 kg HDR**  
**Explosive Test**

C.A. Kot, M.G. Srinivasan, D.K. Vaughan, and J.  
Isenberg  
Argonne National Lab., Argonne, IL, Rept. No. ANL-  
82-53, 117 pp (Nov 1982)  
NUREG/CR-2918

**Key Words:** Interaction: soil-structure, Containment struc-  
tures, Nuclear reactors, Blast response, Computer programs,  
Dynamic tests

This report summarizes a nonlinear 3-D finite-element, soil-structure interaction analysis of dynamic response to a 5 kg explosive blast test performed on the containment building of the Heissdampfreaktor in Germany in 1979. The modeling of the explosive source, site, and building for use in the TRANAL computer code was partially based on information obtained from previous tests. Comparison of analytical results with the test measurements shows that the analysis simulates superstructure response better than it does the foundation response.

**83-1300**

**Modal Analysis and Random Vibration Test of a Nuclear Fuel Assembly**

R.G. Hill and J.F. Patterson  
Exxon Nuclear Co., Intl. Modal Analysis Conf.,  
Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons.  
Union College, Schenectady, NY, pp 103-109, 5  
figs, 1 ref

**Key Words:** Nuclear fuel elements, Natural frequencies, Mode shapes, Finite element technique, Vibration tests

Full scale random vibration tests are performed on a nuclear fuel assembly to determine its vibrational properties for use in verifying analytical models that are subsequently used in earthquake and LOCA (loss-of-coolant accident) vibration analyses.

**OFF-SHORE STRUCTURES**

(Also see No. 1489)

**83-1301**

**Offshore Structures, 1974 - December, 1982 (Citations from Oceanic Abstracts)**

NTIS, Springfield, VA, 212 pp (Dec 1982)  
PB83-855635

**Key Words:** Off-shore structures, Fatigue tests, Bibliographies

This bibliography contains 264 citations concerning safety considerations and disaster prevention for offshore structures. Citations include studies of the dynamic behavior of the structures, fatigue and failure analyses, structural and

safety monitoring techniques and systems, and survival techniques and training.

**83-1302**

**True Ice Force by Deconvolution**

M. Määttänen  
Univ. of Oulu, Oulu, Finland, Intl. Modal Analysis  
Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL.  
Spons. Union College, Schenectady, NY, pp 586-590,  
7 figs, 5 refs

**Key Words:** Ice, Off-shore structures, Modal tests, Transfer functions, Finite element technique

Moving ice exerts high static and dynamic loads against fixed offshore structures. To justify design criteria ice force in-field measurements are needed. However, it is not possible to measure ice forces directly. With slender structures the dynamic response interferes in the measurement signal. The effects of dynamic response of the structure can be removed by deconvolution. This paper presents methods in using transfer functions and deconvolution for analyzing ice force measurement signals from steel lighthouses.

**83-1303**

**Feasibility of Structural Integrity Monitoring of Off-shore Platforms Using Vibration Analysis**

G. Witte  
GKSS - Forschungszentrum Geesthacht GmbH,  
Geesthacht-Tesperhude, Fed. Rep. Germany, Rept.  
No. GKSS-80/E/42, CONF-8009228-1, 11 pp (1980)  
(Intl. Congress on Marine Research and Marine Tech.  
(Intermaritec '80), Hamburg, Fed. Rep. Germany,  
Sept 24, 1980)  
DE82902158  
(In German)

**Key Words:** Monitoring techniques, Signature analysis, Off-shore structures, Drilling platforms

The feasibility of strength monitoring of offshore platforms by analyzing their vibration behavior has been investigated. This so called signature analysis is a new tool for early fault detection and for the near future it can be expected that this method will partially substitute conventional inspection techniques; e.g., the visual checking of structures by divers. Some fundamental aspects of structural failures and their origin are presented.

# VEHICLE SYSTEMS

## GROUND VEHICLES

(Also see Nos. 1339, 1412, 1418)

**83-1304**

### **Digital Modal Analysis Applied to Steering Wheel Vibration**

L. Enochson and D. Galyardt

Time Series Associates, Spokane, WA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 566-572, 13 figs, 2 tables

**Key Words:** Automobiles, Steering gear, Modal tests, Modal analysis

An automobile with high performance suspension, wheels and tires installed experienced moderate to severe steering wheel shake at road speeds of 55, 65 and 90 mph. Modal testing and structural modification analyses were performed using a mini-computer based spectral analyzer. The results of these test and analyses indicated that both the frame crossmember, onto which the steering rack was bolted, and the transmission mount bracket required stiffening. Installation of stiffened components on the automobile significantly alleviated steering wheel shake.

**83-1305**

### **Dynamic Problems in Vehicle Transmission Design**

D. Barbiero, A. Garro, and V. Vullo

FIAT Auto S.p.A. - Direzione Tecnica - Sviluppo Progetti, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 278-288, 17 figs, 10 refs

**Key Words:** Power transmission systems, Automotive transmissions, Drive line vibration, Flexural vibration, Modal analysis

The dynamic problems of motion transmission from gearbox to wheels due to the modal shapes of vibration of the system, when they come within ranges of excitation of the engine, cardanic joints, transmission, centrifugal force, etc., are examined. The analysis is carried out with discretization methods and modal analysis.

**83-1306**

### **The Effect of Two Point Contact on the Curving Behavior of Railroad Vehicles**

J.A. Elkins and H. Weinstock

The Analytic Sciences Corp., Reading, MA, ASME Paper No. 82-WA/DSC-13

**Key Words:** Interaction: rail-wheel

This paper describes recent improvements in the prediction of wheel/rail forces. These improvements are associated with the analytic modeling of the two point contact conditions that exist with the standard wheel and rail profiles in common use in the U.S.

**83-1307**

### **Modal Characterization of a 70-Ton Railroad Boxcar Using a Vibration Test Unit**

F.D. Irani and N.G. Wilson

Boeing Services International, Inc., Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 72-81, 13 figs, 6 tables, 4 refs

**Key Words:** Railroad cars, Box cars, Vibration tests, Test facilities

A Vibration Test Unit (VTU) which is designed for dynamic testing of rail vehicles is described. The facility is capable of inputting periodic, as well as random waveforms and track geometry time histories, to excite a test object. The test unit is controlled and can operate each of its 12 actuators, 8 verticals, one for each wheel, and 4 laterals, one for each axle, simultaneously. Since it is capable of independently controlling any of the actuators with relative time and phase delays the VTU is able to excite a test object in the vertical, lateral, torsional, roll, pitch and yaw modes. This paper presents the details of a modal test and analysis and the results of this investigation. A 70-ton railroad boxcar was tested in two different truck suspension configurations, with and without friction snubbers.

**83-1308**

### **Railroad Vehicle Dynamic Testing Capability and Success**

D.W. Inskeep and J.A. Roberts

Boeing International Inc., Pueblo, CO, ASME Paper No. 82-WA/RT-9

**Key Words:** Railroad trains, Dynamic tests, Vibration tests, Test facilities

This paper describes the capability of the Rail Dynamics Laboratory at the DOT Test Center, in Pueblo, Colorado to perform roll dynamics and low frequency vibration testing of railroad vehicles, describes performed testing and its results, and describes application of laboratory capability to nonrailroad vehicle test articles.

## **SHIPS**

(See No. 1334)

## **AIRCRAFT**

(Also see No. 1412)

### **83-1309**

#### **Flight Effects of Fan Noise**

D. Chestnutt

NASA Langley Res. Ctr., Hampton, VA, Rept. No. L-15493, NASA-CP-2242, 128 pp (Sept 1982) (Presented at the Workshop on Res. on the Simulation of In-Flight Fan Noise and Flight Effects, Hampton, VA, Jan 26-27, 1982)  
N83-10883

**Key Words:** Aircraft noise, Fan noise, Flight simulation

Simulation of inflight fan noise and flight effects was discussed. The status of the overall program on the flight effects of fan noise was reviewed, and flight to static noise comparisons with the JT15D engine were displayed.

### **83-1310**

#### **Ground Effects on Aircraft Noise for a Wide-Body Commercial Airplane**

W.L. Willshire, Jr.

NASA Langley Res. Ctr., Hampton, VA, J. Aircraft, 20 (4), pp 345-349 (Apr 1983) 9 figs, 10 refs

**Key Words:** Aircraft noise

A flight experiment was conducted to investigate ground effects on noise from an airplane with a high-bypass-ratio engine. A Boeing 747 was flown at altitudes of 30-960 m past a 20 microphone array. Ground effects are calculated

in terms of one-third-octave band spectra and in terms of EPNL units. The 747 experimental results are compared with previous results for a turbojet-powered T-38 airplane and with the SAE recommended empirical lateral attenuation prediction procedure. Theoretical predictions are compared with the 747 and T-38 results. Good agreement was found between the predictions and measured results.

### **83-1311**

#### **Aircraft Dynamic Response to Damaged and Repaired Runways**

AGARD, Neuilly-sur-Seine, France, Rept. No. AGARD-CP-326, 227 pp (Aug 1982)  
AD-A122 061

**Key Words:** Aircraft response, Runway roughness

During 1981 and 1982 the AGARD Structures and Materials Panel held two technical meetings on "Aircraft Dynamic Response to Damaged and Repaired Runways." The 1981 meeting focused on the environment of damaged airfields, while the 1982 Specialists' Meeting focused on aircraft dynamic response. The meetings had two main goals: to review the programs and methods within the AGARD countries for dynamic analysis and testing of taxiing aircraft, and to encourage the exchange of information on aircraft dynamic response, thereby improving the interoperability of NATO military aircraft. The publication consists of the papers presented at these meetings.

### **83-1312**

#### **Investigation of Landing Gear Alternatives for High Performance Aircraft**

A.R. DeWispelare and R.P. Stager

Air Force Inst. of Tech., Wright-Patterson AFB, OH, J. Aircraft, 20 (4), pp 319-326 (Apr 1983) 14 figs, 6 tables, 9 refs

**Key Words:** Aircraft, Landing gear, Runway roughness

In an effort to improve rough field performance for a specific high performance aircraft, the modeling of runway profiles, the aircraft structure, landing gears, and aerodynamics was accomplished. Various load alleviation schemes are modeled and then combined with the aforementioned runway and aircraft models into a dynamic simulation which allows the evaluation of the control schemes through numeric and graphical means. These combined evaluation tools (numeric and graphic) add efficiency to the design process along with increasing physical insight into the problem.

**83-1313**

**Dual Input Estimation of Frequency Response Functions for Experimental Modal Analysis of Aircraft Structures**

R.J. Allemang, R.W. Rost, and D.L. Brown  
Univ. of Cincinnati, Cincinnati, OH 45221, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 333-340, 9 figs, 9 refs

**Key Words:** Aircraft, Frequency response function, Modal analysis

The accurate measurement of the frequency response function is vital to the estimation of the system modal parameters. The use of the single input/output theory to formulate the equations for the frequency response function can be replaced by an equivalent theory involving multiple inputs. The results of this approach provide frequency response functions that are comparable to the single input/output case but with a reduction in the time required per measurement and an increase in the consistency of modal frequency and damping values estimated from different frequency response functions. Examples are included for representative aircraft structures.

**83-1314**

**Getting the Most Out of Commercial Modal Systems**

R.G. Smiley  
Entek Scientific Corp., Cincinnati, OH, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 341-347, 8 figs

**Key Words:** Modal analysis, Measuring instruments

This paper reviews some of the characteristics of "canned" modal analysis systems and presents some simple techniques that can be used to greatly enhance the capabilities of (and increase confidence in) their use. Examples include illustrations of problems encountered due to the lack of rotational degrees-of-freedom capabilities and ways to avoid these problems; computation of joint and boundary conditions from simple experimental data, including connection points where no data exists; a strategy for designing products to make them more amenable to analysis; and some reasons for the difficulties encountered in predictive analysis.

**83-1315**

**Application of Dual Input Excitation Techniques to the Modal Testing of Commercial Aircraft**

G.D. Carbon, D.L. Brown, and R.J. Allemang  
Boeing Commercial Airplane Co., Seattle, Washington 98024, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 559-565, 7 figs, 6 refs

**Key Words:** Aircraft, Modal tests, Vibration tests, Testing techniques, Flutter

This paper describes a new multi-exciter ground vibration testing system and procedure used for testing large commercial aircraft. The testing method uses uncorrelated multi-input random excitation with an extensive digital data acquisition system to significantly reduce the testing time and at the same time improve the quality of the modal data base.

**83-1316**

**A Multiple Sine Excitation Approach to Ground Vibration Testing**

C.E. Brickley  
McDonnell Aircraft Co., P.O. Box 516, St. Louis, MO 63166, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 82-87, 10 figs

**Key Words:** Aircraft, Vibration tests, Testing techniques, Sine mask technique

The ground vibration test technique utilized on full-scale aircraft for many years at McDonnell Aircraft Company had been that of swept sine and dwell using multiple vibration exciters. With the advent of real time analyzers, using the fast Fourier transform, a new testing technique needed to be developed which could take advantage of the new potential offered by these data systems. The technique developed combined the proven advantages of swept sine testing with the random data approach required by real time analyzers. The approach, described here and termed "sine mask," involves using a series of sine signals which, through proper combining, create a high energy narrow band signal capable of exciting the test structure at up to six modal frequencies at one time. The vibration introduced into the test structure can be controlled better since multiple exciters are utilized.

**83-1317**

**Digital Modal Analysis of a Full Scale Twin Engine Aircraft**

L. Enochson and R.L. Howes  
Time Series Assoc., Spokane, WA, Intl. Modal Analy-

sis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 95-101, 5 figs, 1 table, 6 refs

**Key Words:** Aircraft, Vibration tests, Random excitation, Impact tests

A ground vibration test on a twin engine aircraft is described. Single point random and impact excitation were used. The data was acquired and analyzed using a high-speed mini-computer. Results were extracted using complex exponential and least squares circle fit algorithms.

### 83-1318

#### Transport Aircraft Crash Dynamics

G. Wittlin, M.A. Gamon, and D. Shycoff  
Lockheed-California Co., Burbank, CA, Rept. No. NASA-CR-165851, 470 pp (Mar 1982)

**Key Words:** Crash research (aircraft), Aircraft

A review and evaluation of transport airplane accident data for the 1964 - 1979 period is presented. Included in the results are formulation of candidate crash scenarios, the identification of the involvement of structural systems and subsystems in transport airplane accidents, a review of existing design criteria and philosophy, and conclusions and recommendations for future R&D effort.

## MISSILES AND SPACECRAFT

(Also see Nos. 1347, 1363, 1378)

### 83-1319

#### Experimental Modal Analysis of the Titan 34D/IUS Payload Fairing

A.G. Ripple and J.R. Janczy  
Martin Marietta Corp., Denver, CO, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 410-416, 15 figs, 10 tables

**Key Words:** Spacecraft, Modal analysis, Modal tests, Swept sine wave excitation, Transfer functions, Random excitation

A modal survey test of the Titan 34D/IUS Payload Fairing (PLF) was conducted to characterize the PLF dynamic properties and to use the results to verify/modify the PLF dynamic model to be used in payload load studies. Two methods of

modal testing were employed: normal mode testing using multi-point swept sine wave excitation, and transfer function testing using single point broad-band random excitation.

### 83-1320

#### Development of Test-Derived Strain Modal Models for Structural Fatigue Certification of the Space Shuttle Orbiter

J.W. Young and J. Joanides  
Structural Dynamics Res. Corp., San Diego, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 479-487, 6 figs, 14 refs

**Key Words:** Spacecraft, Space shuttles, Fatigue life, Modal tests, Frequency response function

A method of predicting strain using a modal model derived from test data is presented. A modal test is performed, and frequency response functions are collected from accelerometers and strain gages. A combined modal model is extracted in which the eigenvectors included both displacement and strain mode shape coefficients. An example application of such test-derived strain modal models to the fatigue evaluation of the space shuttle orbiter is presented.

## BIOLOGICAL SYSTEMS

### HUMAN

### 83-1321

#### Sleep Disturbance Before and After Traffic Noise Attenuation in an Apartment Building

E. Ohrstrom and M. Bjorkman  
Dept. of Environmental Hygiene, Univ. of Gothenburg, Box 33031, S-400 33 Gothenburg, Sweden, J. Acoust. Soc. Amer., 73 (3), pp 877-879 (Mar 1983) 1 table, 10 refs

**Key Words:** Traffic noise, Human response, Noise reduction

A study on traffic noise sleep disturbance was made in an apartment building before and after the installation of noise insulating windows. Three tenants completed a ques-

tionnaire each morning one week before and one week after the insulation of windows, and body movements during sleep were recorded during these periods. The results suggest that subjectively judged sleep quality as well as recordings of bed movements are useful tools for evaluating actions to reduce noise.

## MECHANICAL COMPONENTS

### ABSORBERS AND ISOLATORS

**83-1322**

#### **Experimental-Theoretical Study of Active Vibration Control**

W.L. Hallauer, Jr., G.R. Skidmore, and L.C. Mesquita  
Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 39-45, 10 figs, 20 refs

**Key Words:** Active vibration control, Beams, Suspended structures

The objectives of this research are design and execution of experiments in active vibration control, and quantitative comparison of experimental measurements of control system performance with theoretical predictions. This paper is a report of the initial results. The structure analyzed experimentally and theoretically was a beam suspended by cables in tension. The paper presents experimental results and corresponding theoretical predictions.

**83-1323**

#### **Vibration Absorption of Bridge Cranes During Load Pick Up (Schwingungsdämpfung an Brückenkränen beim Hub mit Lastaufnahme)**

D.N. Spizyna and W. B. Bulanow  
Hebezeuge und Fördermittel, 22 (12), pp 360-363 (1982) 4 figs, 7 refs  
(In German)

**Key Words:** Cranes (hoists), Vibration absorption (equipment)

Vibration absorption of bridge cranes by means of hydraulic absorbers is investigated. Hydraulic vibration absorbers are mounted on both of the main girders of the crane symmetrically to the axis of the crane. By means of this procedure vibration is reduced by about 25-30%.

**83-1324**

#### **Some Aspects of the Design of a Frictionally Damped Absorber**

L.J. Wilkins and S.W.E. Earles  
City Univ., London, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 31-43, 12 figs, 10 refs

**Key Words:** Vibration absorption (equipment), Coulomb friction

The principle of the undamped vibration absorber is well established and the theory of such an absorber has been extended to damped systems to demonstrate the resulting benefits of reduced vibration levels over a wider frequency range. Damping may be achieved in an absorber by the introduction of interfaces at which energy may be dissipated by small relative displacement between mating parts. It is this slip damping which forms the subject of this paper.

**83-1325**

#### **How to Select Isolators for a Long Service Life**

R. Racca  
Barry Controls, Barry Wright Corp., Watertown, MA, Des. News, 38 (1), pp 43-46, 48 (Jan 4, 1982) 6 figs

**Key Words:** Isolators, Shock isolators, Vibration isolators

The factors to be considered in the selection of elastomers are discussed. They are: product application; personnel and equipment protection; sources of vibration, shock and noise, as well as smaller environmental effects; recommended spring rate and frequency of the support structure; type of loading; type of elastomer; internal heat buildup in the elastomer under resonant conditions; and stress and strain on the mount.

**83-1326**

#### **Vibration Isolation Mounts**

R.L. Marinello, editor  
Plant Engrg., 37 (4), pp 36-40 (Feb 17, 1983) 8 figs

**Key Words:** Vibration isolation, Mountings

Some of the more common methods used to control vibration in industrial plants are reviewed. They represent a wide variety of mounts and materials that have been developed to solve specific problems.

**83-1327**  
**Effective Isolation is Answer to Shock, Vibration Questions**

C. Gilbert and H. LeKuch  
Aeroflex Labs., Inc., Plainview, NY, Indus. Res. Dev., 25 (2), pp 172-175 (Feb 1983) 3 figs

**Key Words:** Shock isolators

The authors briefly introduce the fundamentals of shock vibration and discuss typical vibration isolators, such as elastomers, wire rope, and cable isolators. They also consider the effects of temperature, drift, and creep, as well as the most desirable and important characteristics an isolator should have to perform well in severe service conditions.

**83-1328**  
**Vibration Isolation in the Low and High Frequency Range**

G.R. Tomlinson  
Manchester Univ., UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 21-29, 7 figs, 1 table, 4 refs

**Key Words:** Vibration isolation, High frequencies, Low frequencies, Springs, Metals

An experimental investigation of the high and low frequency vibration transmission properties of metal springs is made. Several unusual phenomena are observed and it is shown that recourse to classical theory for longitudinal wave transmission does not account for these phenomena. The theoretical approach used employs the four-pole parameter method and it is shown that this is not sufficient for accurate representation of the transmission behavior of helical springs. If the transverse properties of the springs are considered, a satisfactory explanation of the phenomena is possible.

**83-1329**  
**Vibration Isolation of Pulverising Mills**

D. Malam, J.P. Newell, and G.P. Roberts  
Atkins Res. and Dev., Epsom, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 135-147, 8 figs

**Key Words:** Vibration isolation, Isolators, Industrial facilities

This paper describes the analysis and evaluation of isolation systems for pulverizing mills by measurement and analysis of vibration response and by the use of a rigid body mathematical model with six degrees of freedom. Methods for analyzing and modeling the rocking response of the system due to random excitation using spectral techniques, are outlined. The model has shown good correlation with the measured vibration response, and given a better understanding of the dynamic forcing, damping of the mounting system, inertia block shape and the effectiveness of different spring mountings.

**83-1330**  
**Testing and Analysis of Complex Non-Modal Axial Elements**

H.D. Sigel and G.C. Pardoen  
Newport Corp., Fountain Valley, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 53-58, 11 figs, 8 refs

**Key Words:** Vibration isolation, Testing techniques, Transfer functions, Frequency-dependent parameters

The application of the classical differential equations of motion for a rigid body was found to be unsatisfactory in determining accurate natural frequencies and mode shapes for a structure supported by one or more complex isolation elements. The transfer functions of the element were found to have frequency dependent stiffness and damping as well as varying as a function of the isolator's pre-load. Hence, a method of generating an element model experimentally was needed in order to obtain an accurate systems analysis. A general testing technique is presented which allows accurate determination of the element's transfer function under any arbitrary pre-load. The testing technique involves constraining one end of the axial isolator and measuring the force developed at this point when a displacement (impact, sine or random) is applied at the free end of the element. The experimental transfer function data is acquired with commercially available hydraulic shaker systems and digital Fourier analyzers.

83-1331

**Random Vibration Isolation of Instrumentation During Installation (Schwingungsisolierung von Geräten bei zufälligen Schwingungen am Aufstellungsart)**

H. Tersch

TH Ilmenau, Sektion Geratetechnik, German Dem. Rep., Feingeratetechnik, 32 (1), pp 27-28 (1983)

3 figs, 2 refs

(In German)

**Key Words:** Vibration isolation, Foundations, Instrumentation, Random excitation

Equations for the calculation of the relationship between random excitation and the vibration of instrumentation, especially precision instrumentation, are presented.

83-1332

**Nonlinear Models for Mechanical Seismic Snubbers**

D.P. Reddy and M.S. Agabian

Agabian Associates, El Segundo, CA, ASME Paper No. 82-WA/PVP-3

**Key Words:** Snubbers, Seismic design, Piping systems

This paper describes the development of a detailed snubber process model. The responses of these nonlinear models are compared with the available test data in the form of Lissajous patterns and dynamic time histories showing good agreement between model and experiment. Simplified models are then developed from the nonlinear models for use in the mathematical analyses of piping systems.

83-1333

**A Fluid Dynamic Vibration Absorber**

J.B. Hunt and A.J. McGill

Univ. of Southampton, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 109-124, 12 figs, 1 table, 10 refs

**Key Words:** Vibration absorption (materials), Low frequencies, Fluids, Dynamic vibration absorption (equipment)

The absorption of large amounts of energy at low frequencies by the use of an auxiliary mass-spring system necessitates the use of large masses and soft springs. Apart from the physical

difficulty of handling blocks of concrete and the permanence of it, there can be problems in precisely tuning such a system. For these reasons it was decided to investigate the use of a fluid as the absorber mass, which would be supported on an air spring. The paper reviews earlier work in this area and outlines the theoretical and experimental development of a model absorber, particularly emphasizing the problem of estimating the absorber damping coefficient.

83-1334

**A Damped Vibration Absorber to Reduce Ship Hull Vibration**

G. Long and P.A. Farrell

Aeronautical Research Labs., Melbourne, Australia, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 43-57, 11 figs, 3 refs

**Key Words:** Dynamic vibration absorption (equipment), Vibration absorption (equipment), Ship hulls, Damped structures

A damped vibration absorber of mass 10 ton has been installed in a number of landing craft operated by the Royal Australian Navy. These ships have blunt bows and experience very severe hull vibration, primarily in the two-node vertical mode, when operated in heavy seas. The vibration absorber has increased the damping in the ship and effectively reduced the levels of vibration. The paper describes briefly the absorber design and installation.

83-1335

**Dynamic Vibration Absorber Applications in Industrial Noise Control**

P.M. Wilson

Lucas Industries Ltd., UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 81-85, 5 figs, 3 refs

**Key Words:** Vibration absorption (equipment), Dynamic vibration absorption (equipment), Noise reduction, Vibration control, Case histories

Industrial applications of dynamic vibration absorbers, particularly with respect to retrospective noise and vibration control are very scarce. This paper outlines two practical

applications that have been successfully implemented. It is concluded that, although usually overlooked in some cases, dynamic vibration absorbers can provide an effective retrospective noise control technique with advantages over more traditional noise control measures such as enclosures. These advantages include access, maintenance, cost and engineering elegance.

**83-1336**

**Performance of a Non-Linear Vibration Absorber Attached to a Multi-Degree of Freedom System**

J.B. Hunt and K.G. Lea

Univ. of Southampton, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 125-134, 10 figs, 9 refs

**Key Words:** Vibration absorption (equipment), Multidegree of freedom systems

It is shown that when an absorber is attached to a multi-degree-of-freedom system the suppression band can be increased considerably depending on the tuning of the absorber relative to the resonant frequencies of the main system. If the absorber is tuned below the dominant mode, a non-linear softening spring absorber will increase the suppression band, and for an absorber tuned above the dominant mode a softening spring absorber is less beneficial than a linear absorber.

**83-1337**

**A Design Procedure for Absorbers**

G.B. Warburton

Univ. of Nottingham, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 59-70, 4 figs, 3 tables, 7 refs

**Key Words:** Absorbers (equipment), Vibration absorption (equipment), Design techniques

When excitation causes large dynamic magnification factors in a system, the addition of a properly designed and located absorber will produce significant reductions. The procedure is applicable to systems which are lightly damped and have

well separated natural frequencies. The design criterion is to reduce amplitudes of steady-state vibration at excitation frequencies in the vicinity of one resonance (probably, but not necessarily, the fundamental) with the proviso that the other resonances lie outside the range of excitation frequencies. The absorber, which consists of a damped single degree-of-freedom system, should be attached to the main system, where its amplitude is a maximum (or reasonably large if the position of maximum amplitude is inaccessible). The mass of the absorber should be as large as practical circumstances permit. With the introduction of the absorber there are two resonant peaks in the vicinity of the original resonance and it is required to minimize both these peaks.

**TIRES AND WHEELS**

(Also see No. 1346)

**83-1338**

**Wheel Tread Profile as a Rail Vehicle Design Parameter**

N.K. Cooperrider and J.L. Wirth

Arizona State Univ., Tempe, AZ, ASME Paper No. 82-WA/DSC-3

**Key Words:** Wheels, Railway wheels, Suspension systems (vehicles)

The dynamic performance of vehicles with low, moderate, and high conicity wheel profiles is reported. Design charts for stability and curving are utilized to find optimum primary suspension values to accompany each wheel profile.

**83-1339**

**Comparative Performance Analysis of Conventional and Damper Coupled Wheelsets**

R.V. Dukkipati, B.M. Bahgat, and M.O.M. Osman  
National Res. Council of Canada, Ottawa, Canada,  
ASME Paper No. 82-WA/RT-13

**Key Words:** Wheelsets, Railway wheels, Stability

The dynamic instability of a railway wheelset is caused by the combined action of the conicity of the wheels and the creep forces acting between the wheels and rails. In this paper, the instability is investigated for both the conventional wheelset and the damper coupled wheelset.

## BLADES

(Also see No. 1370)

83-1340

### Analytical and Experimental Investigation of Turbine Blade Damping

R.J. Dominic, P.A. Graf, and B.B. Raju  
Res. Inst., Dayton Univ., OH, Rept. No. UDR-TR-82-39, AFOSR-TR-82-0911, 57 pp (Aug 1982)  
AD-A120 470

**Key Words:** Blades, Turbine blades, Friction damping

Simulated blade to disk damping of a model turbine blade was evaluated, both experimentally and analytically. Experimental work was performed with a unique apparatus that introduced friction damping at the blade platform. Analytical work was performed with a computer program based on the lumped mass theoretical analysis developed by Muszynska and Jones. A test was performed also to evaluate the coefficient of friction at the test setup conditions.

83-1341

### Turbofan Engine Blade Pressure and Acoustic Radiation at Simulated Forward Speed

J.S. Preisser, J.A. Schoenster, R.A. Golub, and C. Horne  
NASA Langley Res. Ctr., Hampton, VA, J. Aircraft, 20 (4), pp 289-297 (Apr 1983), 21 figs, 12 refs

**Key Words:** Blades, Fan blades, Turbofan engines, Sound propagation

Tests were conducted on a JT15D-1 turbofan engine both statically and at simulated forward speed in the Ames 12x24 m wind tunnel. Both far-field acoustic data and unsteady pressure data from transducers mounted on the fan blades were acquired. Results showed a sound power reduction of about 10 dB in the far-field acoustic levels with simulated forward speed over that measured without forward speed. Blade-mounted transducer results showed rotor-turbulence interaction dominated the noise field at very low speeds while an interaction between the rotor and internal struts dominated at higher speeds.

83-1342

### Friction Damping of Flutter in Gas Turbine Engine Airfoils

A. Sinha and J.H. Griffin

Carnegie-Mellon Univ., Pittsburgh, PA, J. Aircraft, 20 (4), pp 372-376 (Apr 1983) 11 figs, 12 refs

**Key Words:** Gas turbines, Blades, Flutter, Coulomb friction

This paper investigates the feasibility of using blade-to-ground friction dampers to stabilize flutter in blades. The response of an equivalent one mode model in which the aerodynamic force is represented as negative viscous damping is examined to investigate the following issues: the range of amplitudes over which friction damping can stabilize the response, the maximum negative aerodynamic damping that can be stabilized in such a manner, the effect of simultaneous resonant excitation on these stability limits, and the determination of those damper parameters which will be the best for flutter control.

83-1343

### Shock Waves Ahead of a Fan with Nonuniform Blades

A.M. Cargill  
Leeds Univ., Leeds, UK, AIAA J., 21 (4), pp 572-578 (Apr 1983) 7 figs, 15 refs

**Key Words:** Blades, Fan blades, Shock wave propagation

When a fan operates at supersonic tip speeds, shock waves are generated ahead of the blades. If these blades are nonuniform, then the shock waves are also nonuniform, and tones at harmonics of the fan rotational frequency are generated. This paper presents a simple theory for the relation between the strengths of the individual shock waves, the blade stagger angles and the blade thicknesses, when the shock wave is detached from the blade leading edge. The results of the theory are in good agreement with experiments and so provide a theoretical basis for the blade shuffling procedures used to minimize blade-to-blade variations and to control shaft order tone generation by these variations.

## BEARINGS

(Also see No. 1459)

83-1344

### Displacement Path of a Dynamically Loaded Plain Radial Bearing (Verlagerungsbahn eines dynamisch belasteten Radialgleitlagers)

I. Teipel and A. Waterstraat  
Institut f. Mechanik der Universität Hannover, Fed. Rep. Germany, Konstruktion, 35 (1), pp 11-15 (Jan 1983) 9 figs, 12 refs  
(In German)

**Key Words:** Bearings, Radial bearings, Plain bearings, Force coefficients

The dynamic force equilibrium required for the calculation of deflection is presented. Thus a new parameter is obtained, which includes the masses of the moving bearing portions. In addition, the deviations from an isothermal case are tested. A satisfactory agreement between the calculated and measured data is obtained.

**83-1345**

**Roller Bearings with Longer Life**

W.L. Bowen

Bowen Consulting, Harwinton, CT, Mach. Des., 55 (5), pp 227-231 (Mar 10, 1983) 6 figs

**Key Words:** Bearings, Roller bearings

Microfinishing of industrial bearings could increase their dynamic load capacity by 30%, or a 250% increase in life. In the article, two ways of microfinishing are described, and the improved dynamic performance characteristics are discussed. Applications range from automotive wheels and axles to computer disc drives.

**83-1346**

**The Effect of Side Bearing Clearance on Vertical Wheel Forces**

P.A. Tombers and R.P. Sellberg

Trailer Train Co., Chicago, IL, ASME Paper No. 82-WA/RT-7

**Key Words:** Bearings, Wheels, Damping

An analysis is completed concerning the effect of side bearing clearance on the vertical wheel forces for a 70 ton boxcar. This analysis includes the effect of track cross level, track stiffness, constant damped truck, variable damped truck and roll angle on the side bearing clearance versus vertical wheel force relationship.

## **FASTENERS**

**83-1347**

**Evaluation of Mounting Bolt Loads for Space Shuttle Get-Away-Special (GAS) Adapter Beam**

D.C. Talapatra and D.J. Hershfeld

Environmental Test and Integration Branch, Engrg. Services Div., NASA Goddard Space Flight Ctr., Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 390-395, 12 figs, 6 refs

**Key Words:** Bolts, Spacecraft, Shuttles (spacecraft), Vibration tests

During the prototype vibration tests of the GAS adapter beam, significant impacting of the beam at its support points was observed. The cause of the impacting was traced to gaps under the mounting bolt heads. Because of the nonlinear nature of the response, it was difficult to evaluate the effects which Shuttle launch dynamics might have on the mounting bolt loads. A series of tests were conducted on an electrodynamic exciter in which the transient acceleration time histories, which had been measured during the Space Transportation System-1 launch, were simulated. The actual flight data had to be filtered and compensated so that it could be reproduced on the shaker without exceeding displacement and velocity limitations. Mounting bolt loads were measured directly by strain gages applied to the bolts. Various gap thicknesses and bolt torques were investigated.

**83-1348**

**Earthquake Resistant Tensile Lap Splices**

J.D. Aristizabal-Ochoa

Vanderbilt Univ., Nashville, TN 37235, ASCE J. Struc. Engrg., 109 (4), pp 843-858 (Apr 1983) 12 figs, 2 tables, 33 refs

**Key Words:** Seismic design, Joints (junctions), Fatigue life

A review of current code requirements on lap splices and their limitations in seismic design is presented. A simple analytical model of an embedded bar is examined and correlated with available experimental data. The force transfer mechanisms of lap splices and the effects of properly placed transverse reinforcement to avoid brittle failure are studied.

## **VALVES**

(Also see No. 1384)

**83-1349**

**Experimental Modal Survey - A Case History**

P. Avitabile and H. Robinson

ITT Grinnell Corp., Providence, RI, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando,

FL. Spons. Union College, Schenectady, NY, pp 66-71, 8 figs, 2 refs

**Key Words:** Valves, Nuclear reactor components, Modal tests

Results of an analytical model and an experimental modal survey of a nuclear, safety-related valve assembly are presented. Preliminary experimental investigation revealed two first cantilevered bending modes of the main structure exist at 30 Hz and 47 Hz. Subsequent investigation of all sub-components of the assembly reveal that the 47 Hz mode is the first cantilevered bending mode of the structure and that the 30 Hz mode is due primarily to an internal sub-assembly that also caused the main structure to respond in the shape of the first cantilevered mode. Without testing all sub-components, an improper description of the modal characteristics would have resulted.

### 83-1350

#### **Resonant Frequency Analysis for Extended Structures**

H.M. Fishman

Franklin Res. Ctr., Philadelphia, PA 19103, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 630-635, 8 figs, 4 refs

**Key Words:** Valves, Seismic analysis, Resonant frequencies

The determination that the resonant frequency be sufficiently large for certain structures may permit the use of more economical static rather than dynamic structural analysis methods for seismic qualification. An extended configuration such as a valve yoke with massive actuator is frequently modeled as a cantilever beam with a single lumped mass at its end; the natural frequency being a well known function of the bending stiffness of the beam, length and mass. For actuators with a mass distribution, not readily represented by concentrated mass, this could lead to gross errors in frequency calculation. To demonstrate this, a mathematical model was formulated of a rigid dumbbell supported at the end of a cantilever beam. Closed-form solutions were obtained for natural frequencies of simple cantilever, combined bending-rotation, torsional, and axial modes of vibration. The ratios of these frequencies were presented in terms of the stiffness and geometric parameters.

## **STRUCTURAL COMPONENTS**

### **CABLES**

### 83-1351

#### **Dynamic Analysis of a Low-Cost Catenary System for Electric Railroads**

G.R. Doyle, Jr.

Battelle Columbus Lab., Columbus, OH, ASME Paper No. 82-WA/RT-2

**Key Words:** Catenaries, Transmission lines, Electric railroads

A simplified railroad electrification system has been suggested to reduce the construction and maintenance complexities and cost associated with the conventional collector/conductor system. The new system includes a single-conductor catenary and a collector attached to the conductor by two sets of rotating wheels. This paper outlines the dynamic models, presents the parametric study, and recommends several guidelines to follow in designing the traveler/conductor system.

### 83-1352

#### **Measurement of the Mechanical Characteristics of a Full Scale Transmission Line Conductor Bundle**

S.J. Price

Dept. of Mech. Engrg., McGill Univ., Montreal, Canada, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 396-402, 7 figs, 12 refs

**Key Words:** Transmission lines, Cables, Wind-induced excitation, Aeroelasticity, Vibration measurement, Natural frequencies, Mode shapes, Modal damping

As a result of an aeroelastic investigation of overhead power conductors, the importance of the natural frequencies, mode shapes, and modal damping values for the complete conductor-spacer system has become apparent. In this paper, an attempt to measure these parameters on a full scale experimental transmission line is described.

### 83-1353

#### **Nonlinear Dynamics of Cable Supported Systems**

M.L. Gambhir and B.deV. Batchelor

Thapar Engrg. College, Patiala, India - 147 001, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 656-661, 6 figs, 9 refs

**Key Words:** Cables, Nonlinear systems, Finite element technique

The paper deals with the dynamic analysis of geometrically nonlinear cable structures by finite element techniques. The changes in cable tension and in the geometry of the system are taken into account using nonlinear strain-displacement relationships. The unknown frequencies estimated from the linear equation obtained for a small perturbation of amplitude, reduce the nonlinear vibration problem to an initial value problem solved by successive corrections to the assumed stiffness matrices. A single cable which is a basic component of more complex cable supported systems, is critically analyzed.

## BARS AND RODS

83-1354

### Dynamic Analysis of Mechanical Concentrators and Nonuniform Elements Through Modulation Functions

Y. Frostig, J. Gluck, and G. Rosenhouse

Faculty of Civil Engrg., Technion - Israel Inst. of Tech., Haifa, Israel, Israel J. Tech., 20 (1-2), pp 17-30 (1982) 8 figs, 25 refs

**Key Words:** Rods, Beams, Columns, Modulation functions, Green function

The dynamic behavior of elements such as ultrasonic concentrators, nonuniform parts of machines, beams and columns is investigated. In order to present a general approach the concept of modulation functions is introduced. The relation between these functions - applied as to permit approximations - is demonstrated, and the influence of different nonuniformities on the response of dynamic forced systems is determined with the aid of Green functions. Numerical results of significant examples are represented by appropriate formulas and graphs.

83-1355

### Out-of-Plane Vibrations of Curved Bars with Varying Cross-Section

K. Suzuki, T. Kosawada, and S. Takahashi

Faculty of Engrg., Yamagata Univ., Yonezawa, Japan, Bull. JSME, 26 (212), pp 268-275 (Feb 1983) 17 figs, 13 refs

**Key Words:** Bars, Curved rods, Variable cross-section, Natural frequencies, Mode shapes

The out-of-plane free vibrations of a curved bar of which the cross-section varies, are analyzed using the classical

theory. The equations of vibration and the boundary conditions are determined from the stationary conditions of the Lagrangian of the bar in a period of vibration. The equations of vibration are solved exactly in a series solution. As numerical examples, the natural frequencies and the mode shapes of symmetric elliptic arc bars with both clamped ends and with both simply supported ends are obtained.

## BEAMS

(Also see Nos. 1322, 1354, 1396)

83-1356

### Eigenfrequencies, Mode Shapes and Modal Masses of Beams in Coupled Vibrations - Theory and Experiment

O. Friberg, S. Ohlsson, and B. Akesson

Divisions of Solid Mechanics and Steel and Timber Structures, Chalmers Univ. of Tech., S-412 96 Gothenburg, Sweden, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 147-152, 8 figs, 1 table, 6 refs

**Key Words:** Beams, Natural frequencies, Mode shapes, Coupled response

Beam cross-sections with noncoinciding centers of geometry, shear and mass often occur in practice. Instead of pure tensional, flexural and torsional vibrations, a beam with such a cross-section performs coupled vibrations. A frequency-dependent 12x12 stiffness matrix for a uniform beam element in coupled vibrations under stationary harmonic end excitation can be established by use of an analytic method. Eigenfrequencies and mode shapes of built-up frame structures in space can thereby be determined. It is shown here how modal masses (generalized masses) of these structures can be found from a double-sum (real) of complex-valued terms. Experimental results from a laboratory testing of a space frame model are compared with computed values.

83-1357

### Large Amplitude Vibrations of Moderately Thick Beams

M. Sathyamoorthy

Dept. of Mech. and Industrial Engrg., Clarkson College of Tech., Potsdam, NY 13676, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 136-140, 5 tables, 12 refs

**Key Words:** Beams, Transverse shear deformation effects, Rotatory inertia effects

Moderately thick beams are widely used as structural elements and the study of their dynamic behavior should consider the transverse shear and rotatory inertia effects in the analysis. A review of literature indicates that approximate solutions to this class of problems are very limited and are based on some limited application of the finite element method. In this paper, self-generating functions are used to investigate the nonlinear dynamic behavior of beams accounting for the effects of transverse shear and rotatory inertia. Numerical results for nonlinear frequency ratios are reported for beams with different boundary conditions. Effects of amplitude of vibration, length-to-radius of gyration ratio, boundary conditions as well as coupling between modes are studied.

**83-1358**

**Damped Second-Order Rayleigh-Timoshenko Beam Vibration in Space - An Exact Complex Dynamic Member Stiffness Matrix**

R. Lunden and B. Akesson

Div. of Solid Mechanics, Chalmers Univ. of Tech., Gothenburg, Sweden, Intl. J. Numer. Methods Engrg., 19 (3), pp 431-449 (Mar. 1983) 7 figs, 1 table, 23 refs

**Key Words:** Beams, Rayleigh method, Timoshenko theory, Damped structures, Harmonic response, Matrix methods

A uniform linear beam in a uniform linear ambient medium is studied. The beam performs stationary harmonic damped nonsynchronous space vibration in simultaneous tension, torsion, bending and shear in the presence of a large static axial load. Hysteretic and viscous dampings of the beam material and ambient medium are considered. Generalized complex Koloušek functions are derived.

**83-1359**

**Calculation of Exact Vibration Modes for Plane Grillages by the Dynamic Stiffness Method**

W.L. Hallauer, Jr. and R.Y.L. Liu

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 1-7, 3 figs, 1 table, 10 refs

**Key Words:** Grids (beam grids), Dynamic stiffness, Matrix methods, Flexural vibration, Torsional vibration, Natural frequencies, Mode shapes

The dynamic stiffness method has been used in the past primarily for calculation of exact modal parameters and frequency response of beams, frames, and trusses. The method is extended in this paper to another class of structure composed of one-dimensional members, the plane grillage. An example grillage is defined numerically, and exact modal solutions are presented. Approximate solutions calculated by the finite element method are also presented for comparison.

**83-1360**

**Parametric Instability of Curved Girders**

S.A. Ali

King Abdulaziz Univ., P.O. Box 9027, Jeddah, Saudi Arabia, ASCE J. Struc. Engrg., 109 (4), pp 829-842 (Apr 1983) 3 figs, 21 refs

**Key Words:** Beams, Girders, Curved beams, Pulse excitation, Parametric excitation

The parametric instability of a curved girder subjected to equal and opposite periodic moments at the ends is examined. It is shown that the relationship of the frequencies at which parametric resonance occurs differs from the frequency relationship of ordinary resonance. For small values of the applied couples at the ends, the parametric resonant frequency is twice the natural frequency. The method presented can also be used to determine the natural frequencies and static buckling moment for a curved girder. Special analytical solutions and numerical results are obtained and presented in nondimensional forms.

## CYLINDERS

**83-1361**

**Non-Axisymmetrical Vibrations of a Shell-Stiffened Cylinder**

I. Maljutin and A. Nedbaj

Vibrotechnika, 4 (34), pp 19-24 (1981) 2 figs, 2 refs (In Russian)

**Key Words:** Cylinders, Stiffened structures, Shells, Natural frequencies, Transverse shear deformation effects, Numerical analysis

This report discusses two-dimensional free vibrations of a shell-stiffened elastic cylinder. Transverse shear in the shell is considered. Equations of cylinder motion are reduced to homogeneous and non-homogeneous Bessel's equations by transformation method. Numerical analysis of natural frequency dependence from cylinder inner radius is presented.

83-1362

**Forced Vibrations of a Visco-Elastic Shell-Stiffened Cylinder**

I. Maljutin and A. Nedbaj

Vibrotehnika, 4 (34), pp 25-31 (1981) 3 figs, 4 refs (In Russian)

**Key Words:** Cylinders, Shells, Harmonic excitation, Forced vibration, Viscoelastic properties

The subject of the study is the stress-strained state of a system comprising an orthotropic shell and a hollow isotropic visco-elastic shell-stiffened cylinder subjected to harmonically variable distributed loading. Shell motion is described by technical theory equations. Cylinder behavior is determined by three-dimensional elastic theory equations written in the form of vectors. These equations are solved by Lamé method. Visco-elastic properties of the cylinder are expressed by complex module of elasticity. Problem solution is found in double trigonometric series. A numerical example is given.

**COLUMNS**

(See Nos. 1354, 1396)

**FRAMES AND ARCHES**

83-1363

**Experimental and Theoretical Study of the Gross Deformation Response of Unrestrained Triangular Frames Subjected to Concentrated and Distributed Impulsive Loads**

M.S.J. Hashmi

Dept. of Mech. and Production Engrg., Sheffield City Polytechnic, Sheffield, UK, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 550-558, 12 figs, 6 refs

**Key Words:** Framed structures, Spacecraft, Impulse response

The free flight deformation behavior of triangular frames, subjected to distributed and concentrated impulsive loads, is investigated experimentally. A numerical technique, based on finite difference principles, is used to theoretically predict the elastic-plastic response of the frames. The agreement between the experimental results and those predicted theoretically appears to be reasonably good.

83-1364

**Shear Deformation in Seismic Frame Structures**

R.C. Fenwick

Univ. of Auckland, Auckland, New Zealand, ASCE J. Struc. Engrg., 109 (4), pp 965-976 (Apr 1983) 12 figs, 8 refs

**Key Words:** Framed structures, Buildings, Reinforced concrete, Earthquake response

Inelastic cyclic loading in reinforced concrete members, which may occur in ductile frame structures under severe seismic conditions, causes shear deformation to develop in hinge zones. Experimental results illustrating this are presented.

83-1365

**Structural Frame Vibration Analysis Based on Measured Support Mobilities**

B. Akesson, O. Friberg, and E. Kamph

Div. of Solid Mechanics, Chalmers Univ. of Tech., S-412 96 Gothenburg, Sweden, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 463-476, 20 figs, 15 refs

**Key Words:** Frames, Beams, Machine foundations, Foundations, Modal analysis, Impact tests, Curve fitting, Finite element technique

A resiliently supported plane frame superstructure was constructed. They dynamic properties of this superstructure were calculated by use of the exact displacement finite element method as implemented in the computer program SFVIBAT-DAMP. Measured and calculated data for the separate lower beam and for the resiliently supported superstructure showed a reasonable agreement in the frequency range studied (0-400 Hz) except for the dampings at the four resonance frequencies of the superstructure.

83-1366

**Dynamic Analysis of Rigid Frame Structures Subjected to Non-Linear Earthquake Vibration**

I.C. Chang

College of Staten Island, City Univ. of New York, Staten Island, NY, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 643-648, 7 figs, 21 refs

**Key Words:** Framed structures, Seismic analysis

This paper attempts to establish a mathematical model for the dynamic analysis of rigid frames subjected to nonlinear earthquake vibration. The nonlinear H. Nagaoka seismic equation is investigated by the asymptotic method. The results are compared from the application of two methods: the perturbation technique of Bogoliubov and Mitropolsky and the operational method of Linsted and Liapounoff. An optimization scheme for designing simple rigid frames is suggested. Three possible breakdown mechanisms are taken into consideration: buckling, side-sway, and combined collapse.

83-1367

**Dynamic Stability of a Lattice Dome**

C.H. Coan and R.H. Plaut

Bechtel Power Corp., Los Angeles, CA, Intl. J. Earthquake Engrg. Struc. Dynam., 11 (2), pp 269-274 (Mar/Apr 1983) 7 figs, 12 refs

**Key Words:** Domes, Grids (beam grids), Impulse response

A shallow lattice dome subjected to three independent sets of step or impulse loads is investigated. Symmetric and asymmetric loading distributions are considered. The dynamic response is determined by numerical integration, and critical loads are defined by the Budiansky-Roth criterion. Interaction curves for fixed maximum response and for snap-through instability are obtained, and a comparison is made with previous results for static loading.

## PLATES

83-1368

**Stability of a Rectangular Plate under Nonconservative and Conservative Forces**

S. Adali

National Res. Inst. for Mathematical Sciences, Pre-

toria, South Africa, Rept. No. CSIR-TWISK-245, 28 pp (Jan 1982)

N83-11512

**Key Words:** Plates, Rectangular plates, Flutter

Flutter and divergence instabilities of a rectangular plate with two independent loading parameters are studied. The plate is subjected to the combined action of a tangential follower force and a unidirectional axial force along one edge. Two opposite sides of the plate are simply supported, one side being clamped and the other being a free edge where the inplane forces act.

83-1369

**Geometrically Nonlinear Transient Analysis of Laminated Composite Plates**

J.N. Reddy

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, AIAA J., 21 (4), pp 621-629 (Apr 1983) 14 figs, 27 refs

**Key Words:** Plates, Composite structures, Layered materials, Transient response, Finite element technique, Transverse shear deformation effects, Rotatory inertia effects

Forced motions of laminated composite plates are investigated using a finite element that accounts for the transverse shear strains, rotary inertia, and large rotations (in the von Kármán sense). The present results when specialized for isotropic plates are found to be in good agreement with those available in the literature. Numerical results of the nonlinear analysis of composite plates are presented showing the effects of plate thickness, lamination scheme, boundary conditions, and loading on the deflections and stresses. The new results for composite plates should serve as bench marks for future investigations.

83-1370

**Vibration Analysis of Twisted Plates**

V. Ramamurti and S. Sreenivasamurthy

Dept. of Appl. Mechanics, Indian Inst. of Tech., Madras 36, India, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 303-309, 6 figs, 3 tables, 21 refs

**Key Words:** Plates, Cantilever plates, Flexural vibration, Torsional vibration, Compressor blades, Blades

The trends of variation of the first five frequencies of low aspect ratio cantilever plates with pretwist angle have been studied using three dimensional elements as well as shell elements. Both the analyses agree as far as the trend of variation is considered.

### 83-1371

#### Modal Analysis of Perforated Plates with Triangular Patterns of Circular Holes

S.N. Plyat and A.P. Villazor, Jr.

Nuclear Technology Div., Westinghouse Electric Corp., Pittsburgh, PA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 326-332, 7 figs, 6 tables, 6 refs

**Key Words:** Plates, Hole-containing media, Modal analysis

The concept of equivalent solid plate elaborated for stress-strain problems of perforated plates with triangular penetration patterns is found sufficiently accurate for modal analysis of such plates. The replacement solid plate must be considered anisotropic with the effective elastic constants determined according to the theory by O'Donnell, et al. With any combination of simply supported/fixed boundary condition at the circumference, a maximum discrepancy of about 8% on the first natural frequencies results. This deviation increases to 22% with free/partially free condition at the circumferential edges.

### 83-1372

#### A Study of the Mode Shapes and Natural Frequencies of Two Plates Coupled Together with Radial Stiffeners

A. Gupta and C.E. Passerello

Michigan Technological Univ., Houghton, MI 49931, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 310-318, 2 figs, 3 tables, 3 refs

**Key Words:** Plates, Stiffened plates, Natural frequencies, Mode shapes

This paper examines the mode shapes and natural frequencies of a system composed of two annular plates. The plates are connected by transverse stiffeners located in the radial directions. The boundary conditions are prescribed so that all edges are free except for the inner edge of one of the disks which is fixed. The stiffeners along the radial directions are approximated as line springs.

### 83-1373

#### The Effects of Boundary Conditions on the Vibration of Transverse Isotropic Thick Plates

Lien-Wen Chen, Ji-Liang Doong, and Tin-Yew Ye

Dept. of Mech. Engrg., National Cheng Kung Univ., Tainan, Taiwan, R.O.C., Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 319-325, 9 figs, 1 table, 14 refs

**Key Words:** Plates, Rectangular plates, Finite strip method, Boundary condition effects, Natural frequencies

The free vibration problems of a rectangular thick plate under arbitrary initial stresses are solved by the finite strip method. The initial stresses are taken to be a uniform extensional stress plus a bending stress. The effects of different boundary conditions and various parameters on natural frequencies are investigated.

### 83-1374

#### Vibration of a Plate of Arbitrary Shape with Free and Simply Supported Mixed Edges

K. Nagaya

Dept. of Mech. Engrg., Faculty of Engrg., Gunma Univ., Kiryu, Gunma 376, Japan, J. Acoust. Soc. Amer., 73 (3), pp 844-850 (Mar 1983) 7 figs, 4 tables, 15 refs

**Key Words:** Plates, Natural frequencies, Boundary condition effects

A method for solving vibration problems of a plate of arbitrary shape with free and simply supported mixed edges is presented. In the analysis the exact solution of the equation of motion which includes terms representing the reaction forces of the simply supported edges is applied. The boundary conditions along the edges of arbitrary shape are satisfied directly by making use of the Fourier expansion collocation method. The equation for finding the eigenfrequencies of plates of arbitrary shape with free and simply supported mixed edges is obtained. Numerical calculations are carried out for polygonal plates, trapezoidal plates, truncated elliptical plates, and parabolic plates with mixed edges.

### 83-1375

#### The Influence of Mid-Plane Normal Stress and Cross Section Deformation in Free Vibrating Plates

H. Irretier

Institut f. Mechanik, Universität Hannover, Hannover, Bundesrepublik Deutschland, Mech. Res. Comm., 10 (1), pp 53-61 (Jan/Feb 1983) 6 figs, 2 tables, 7 refs

**Key Words:** Plates, Free vibration

The classical plate-theory, as introduced by Kirchhoff, assumes, in the form of the hypothesis of nondeformable normals, a linear distribution of the in-plane deformation across the thickness of the plate and also neglects the influence of normal stresses with respect to the middle-plate surface. In this paper the influence, in the sense of the two-dimensional plate theory, of the in-plane displacements and normal stresses (the secondary effects) on the eigenfrequencies, eigenforms and stress distributions are investigated. For this purpose a simply supported, free vibrating plate is considered by inserting double Fourier series solutions into the different plate equations and then solving these using a Newton-Raphson iteration method.

**83-1376**

**Dynamic (Transient) Analysis of Layered Anisotropic Composite-Material Plates**

J.N. Reddy

Dept. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, Intl. J. Numer. Methods Engrg., 19 (2), pp 237-255 (Feb 1983) 15 figs, 3 tables, 25 refs

**Key Words:** Plates, Composite structures, Layered materials, Transient analysis

A shear-flexible finite element is employed to investigate the transient response of isotropic, orthotropic and layered anisotropic composite plates. Numerical convergence and stability of the element is established using Newmark's direct integration technique. Numerical results for deflections and stresses are presented for rectangular plates under various boundary conditions and loadings. The parametric effects of the time step, finite element mesh, lamination scheme and orthotropy on the transient response are investigated.

**83-1377**

**Free Vibration of Cantilever Quadrilateral Plates**

R.S. Srinivasan and B.J.C. Babu

Indian Inst. of Tech., Madras-600036, India, J. Acoust. Soc. Amer., 73 (3), pp 851-855 (Mar 1983) 3 figs, 1 table, 15 refs

**Key Words:** Plates, Cantilever plates, Natural frequencies, Mode shapes, Aircraft wings

A numerical method for the free vibration analysis of cantilever quadrilateral plates of general shape is presented. Using quadrilateral coordinates and integral equation of beams, the expressions for the strain energy and kinetic energy are developed. The formulation and derivation of equations are in the matrix form "ab initio." The eigenvalue problem is solved for frequencies and mode shapes.

**SHELLS**

(Also see Nos. 1361, 1362)

**83-1378**

**Dynamic Stability of a Thin Cylindrical Shell Model of a Spin Stabilized Satellite**

W.N. Dong and A.L. Schlack, Jr.

Sperry-Univac, Santa Clara, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL, Spons. Union College, Schenectady, NY, pp 692-697, 4 figs, 3 refs

**Key Words:** Shells, Cylindrical shells, Satellites, Stability

A dynamic stability analysis employing Liapunov's direct method is presented for studying the influence of structural flexibility on the attitude stability of a spin stabilized satellite. The satellite is modeled as a thin elastic circular cylindrical shell attached to a rigid structural frame of finite mass. The Flügge shell theory is employed and the shell's deformations are described by a complete infinite series of functions satisfying boundary conditions.

**83-1379**

**The Structural Analysis of a Solar Furnace**

R.S. Pinkham, III and L.J. LaFrance

General Dynamics Corp., San Diego, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL, Spons. Union College, Schenectady, NY, pp 709-713, 4 figs, 3 tables, 4 refs

**Key Words:** Solar cells, Shells, Modal analysis

The dynamic analysis of a 25.6 meter radar dish converted to a high temperature solar test facility is described. The finite element modeling of the structure is discussed. The mode shapes and eigenvalues are compared to the structure's vortex shedding frequencies.

**83-1380**

**Modal Analysis of Damped Cylindrical Shells with Temperature Dependent Properties**

S.N. Singhal and E.G. Lovell

Shell Development Co., Houston, TX 77001, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 686-691, 2 figs, 4 refs

**Key Words:** Shells, Cylindrical shells, Damped structures, Temperature effects, Modal analysis, Transient response

Modal analysis is used to determine the transient response of isotropic, elastic, thin, damped cylindrical shells with temperature-dependent material properties. Flugge's shell equations are modified to include the temperature-dependence of the elastic modulus and thermal strain coefficient. A perturbation technique is used with small parameters identifying the changes in material properties.

**83-1381**

**Vibration Studies and Tests of Liquid Storage Tanks**

M.A. Haroun

Univ. of California, Irvine, CA, Intl. J. Earthquake Engrg. Struc. Dynam., 11 (2), pp 179-206 (Mar/Apr 1983) 21 figs, 3 tables, 27 refs

**Key Words:** Shells, Storage tanks, Fluid-filled containers, Seismic design, Vibration tests

Theoretical and experimental investigations of the dynamic behavior of ground-supported, deformable, cylindrical liquid storage tanks were conducted. The study was carried out in three phases: a detailed theoretical treatment of the coupled liquid-shell system for tanks rigidly anchored to their foundations; an experimental investigation of the dynamic characteristics of full-scale tanks; and a development of an improved seismic design procedure.

**83-1382**

**Optimum Cone Angles in Aeroelastic Flutter**

P.J. Sunder, C.V. Ramakrishnan, and S. Sengupta  
Dept. of Appl. Mech., Indian Inst. of Tech., New Delhi, India, Computers Struc., 17 (1), pp 25-29 (1983) 2 figs, 4 tables, 5 refs

**Key Words:** Flutter, Aeroelasticity, Conical shells, Shells, Finite element technique

The determination of flutter frequencies and flutter boundary pressures of conical shells is carried out using finite element analysis. Static condensation procedure with Q.R. algorithm is used for the extraction of eigenvalues of the system. An empirical relation for determining the values of flutter boundary pressures of clamped-clamped conical shells is proposed. It is seen that there is an optimum semi-vertex angle at which a given conical shell of prescribed length and initial radius offers maximum resistance for flutter.

**PIPES AND TUBES**

(Also see No. 1332)

**83-1383**

**Acoustically Induced Piping Vibration in High Capacity Pressure Reducing Systems**

V.A. Carucci and R.T. Mueller

Exxon Res. and Engrg. Co., Florham Park, NJ, ASME Paper No. 82-WA/PVP-8

**Key Words:** Piping systems, Noise induced excitation, Resonant response, Fatigue life

This paper describes the causes of high acoustic energy, how it can excite resonant piping vibration and ultimately result in fatigue failures, and provides highlights of failure experience. Correlations are presented based on sound power level, line size and operating experience which may be used to evaluate systems for potential problems.

**83-1384**

**Analysis of Relief/Safety Discharge Loads by Modal Approach**

Zs. Révész

Electrowatt Engineering Services Ltd., CH-8022 Zurich, Switzerland, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 296-302, 7 figs, 10 refs

**Key Words:** Piping systems, Valves, Nuclear power plants, Seismic excitation, Fluid-induced excitation, Substructuring methods

The paper summarizes what has been done to account for dynamic loading associated with Relief/Safety Valve Discharge (R/SVD) and other loads such as weight, thermal effects and seismic loads in a main steam line with attached

R/SVD lines in a boiling water reactor plant. The analysis included the entire portion of the piping. The paper presents an industrial application, in which economy of computation played an important role. The results demonstrate that comprehensive analysis of a complex piping system can be performed economically with modal analysis up to relatively high frequencies.

### 83-1385

#### **A Time-Averaging Transient Testing Method for Acoustic Properties of Piping Systems and Mufflers with Flow**

T.Y. Lung and A.G. Doige

NGL Dept., Dome Petroleum Ltd., Box 200, Calgary, Alberta, Canada T2P 2H8, J. Acoust. Soc. Amer., 73 (3), pp 867-876 (Mar 1983) 20 figs, 27 refs

**Key Words:** Piping systems, Acoustic properties, Mufflers, Testing techniques

A time-averaging transient testing technique has been developed to allow for a rapid measurement of the matrix parameters and other frequency-dependent characteristics of acoustical systems with or without mean flow. The technique is applicable to systems with substantial flow noise contamination which is either random or periodic in nature. Flow and no-flow experiments were conducted on laboratory models of exhaust mufflers, variable area ducts, and complex piping networks.

### 83-1386

#### **Dynamic Behavior of Piping and Supports at High-Load Levels - Experimental Study of a Scaled System**

K. Blakely, P. Ibanez, and S. Griffith

ANCO Engineers, Inc., Culver City, CA, ASME Paper No. 82-WA/PVP-4

**Key Words:** Piping systems, Nuclear power plants, Seismic response, Crash research (aircraft)

A one-third scale model of an existing nuclear power plant piping system and its concrete support points were tested to assess their ability to withstand dynamic loads resulting from an earthquake and from an aircraft impacting the containment structure. Velocity scaling was used, which maintained stress and strain equality between the prototype and the scale model.

### 83-1387

#### **Dynamic Impact Requirements for Design of Pipe Break Whip Restraints**

R.C. Sampson

Bechtel Power Corp., San Francisco, CA, ASME Paper No. 82-WA/PVP-5

**Key Words:** Piping systems, Energy methods, Impact response

This paper describes the application of the energy method to the problem of determining the structural requirements and pipe break performance on the basis of lumped element models. Simple relationships based on the energy-limited forced displacement of several different types of restraints are developed.

### 83-1388

#### **Dynamic Response of Piping Systems at Varying Load Amplitudes: Experimental Studies of Damping**

G.E. Howard, W.B. Walton, D.E. Chitty, P. Ibanez, H.T. Tang, and Y.K. Tang

ANCO Engineers, Inc., Culver City, CA, ASME Paper No. 82-WA/PVP-9

**Key Words:** Piping systems, Nuclear power plants, Variable amplitude excitation, Damping

In 1979 a series of analyses and tests of a nuclear power plant piping system were begun to investigate the dynamic characteristics of such a system. The ultimate goal of the research effort is the development of improved analysis methods for piping systems subjected to dynamic loads. Among the major objectives of the research were investigations of piping system damping and nonlinear phenomena as a function of response amplitude, and the development of benchmark data for validating nonlinear analysis methods.

### 83-1389

#### **Damping in Nonlinear Piping Systems**

D.E. Chitty, G.E. Howard, and W.B. Walton

ANCO Engineers, Inc., Culver City, CA, ASME Paper No. 82-WA/PVP-10

**Key Words:** Piping systems, Damping coefficients

A numerical study was made of various methods for calculating damping from experimental structural response data. It is shown that the various methods can produce signifi-

cantly different damping values. This is a significant result since many, if not most, structural systems encountered in practice have some measurable nonlinearity.

### 83-1390

#### **Seismic Testing and Analysis of a Prototypic Non-linear Piping System**

D.A. Barta, M.J. Anderson, and L.K. Severud  
Westinghouse Hanford Co., Richland, WA, ASME  
Paper No. 82-WA/PVP-6

**Key Words:** Piping systems, Seismic response, Dynamic tests

A series of seismic tests and analysis of a nonlinear Fast Flux Test Facility prototypic piping system are described, and measured responses are compared with analytical predictions.

### 83-1391

#### **Upper Bounds of Modal Representation Applied to Piping Analysis**

M.Z. Lee  
Gilbert/Commonwealth Co., Reading, PA 19603,  
Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10,  
1982, Orlando, FL. Spons. Union College, Schenec-  
tady, NY, pp 272-277, 8 refs

**Key Words:** Modal analysis, Piping systems, Seismic response, Spatial response

Mathematical bases of both modal response analysis in the time and frequency domains, and the method of computing upper bounds of seismic responses by using incomplete eigenvalue solutions, are reviewed. Theoretical justifications are given for the application of those upper bounds to piping analysis. A method of computing an upper bound of spatial response combination is introduced and illustrated by application to the analysis of typical, simple, piping configurations installed in an arbitrarily-rotated orientation.

### 83-1392

#### **A Simplified Methodology for Calculations of Pipe Impacts: Comparison with Tests**

J.-L. Garcia, P. Chouard, and A. Martin  
Commissariat A L'Energie Atomique, France, ASME  
Paper No. 82-WA/PVP-2

**Key Words:** Pipelines, Pipe whip, Finite element technique, Beams

Calculations of pipe whip are performed with the help of a finite element code using a beam formulation. Impact is simulated by introducing the local nonlinear stiffness of the pipe. This resistance curve is obtained by a shell calculation in good agreement with a static crush test.

## **BUILDING COMPONENTS**

### 83-1393

#### **Dynamic Centrifuge Testing of a Cantilever Retaining Wall**

L.A. Ortiz, R.F. Scott, and J. Lee  
Soil Mechanics Lab., Div. of Engrg. and Appl. Sci-  
ence, California Inst. of Tech., Pasadena, CA 91125,  
Intl. J. Earthquake Engrg. Struc. Dynam., 11 (2),  
pp 251-268 (Mar/Apr 1983) 14 figs, 7 tables, 48 refs

**Key Words:** Walls, Dynamic tests

Two correctly-scaled model cantilever retaining walls of different stiffnesses were tested under dynamic loading conditions in a centrifuge. A medium-dense fine sand was retained with a range of backfill slopes. For the centrifuge model, an earthquake-generating mechanism was designed to produce seismic shaking equivalent to that generated at ground surface in the epicentral area of an earthquake of approximate magnitude 5.5. The response of the model retaining walls to the input dynamic motion was measured by strain gauges, pressure transducers and accelerometers. From the measurements plots were constructed of moment, shear, pressure and displacement over the height of the walls as a function of time. The results are compared with calculations based on the quasi-static Mononobe-Okabe theory.

### 83-1394

#### **Response of Structures with Flexible Floor Systems Subject to Vertical Ground Motion**

S.L. Chin, M.P. White, and F.J. Dzialo  
Yankee Atomic Electric Co., Framingham, MA, Intl.  
Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982,  
Orlando, FL. Spons. Union College, Schenectady,  
NY, pp 614-621, 6 figs, 2 tables

**Key Words:** Floors, Nuclear power plants, Ground motion

An analytical method to predict the dynamic response of structures with flexible floor systems, and subject to the

vertical component of a ground motion are developed. Prescribing mode shapes and coordinates which couple the bending and rigid body motion between the floor slabs and elastic columns, and then operating with Lagrange's equations on the respective energies of the system, a set of coupled equations is determined. The resulting equations are uncoupled in mass-stiffness form, and solutions for free and forced vibration are determined by classical normal mode theory. The solutions are applied to an existing nuclear power plant facility. Numerical results giving frequencies, normalized mode shapes, and floor responses for both flexible and rigid slabs due to a suddenly applied ground acceleration are presented.

**83-1395**

**Finite Element Analysis of Reinforced Concrete Structures**

N.G. Sarigül

Istanbul Technical Univ., Turkey, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 26-31, 8 figs, 4 refs

**Key Words:** Structural members, Reinforced concrete, Computer programs, Finite element techniques

A finite element displacement method is developed for the analysis of two dimensional reinforced concrete structures under short time, monotonic loading. It is assumed that cracks of concrete may occur and propagate at the nodes instead of assuming smeared cracks along the whole element. A computer code is developed for the numerical computations. A uniformly loaded reinforced concrete beam is studied as an example.

**83-1396**

**Control of Structures Subjected to Seismic Excitation**

L. Meirovitch and L.M. Silverberg

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, ASCE J. Engrg. Mech., 109 (2), pp 604-618 (Apr 1983) 12 figs, 11 refs

**Key Words:** Seismic excitation, Beams, Columns, Finite element technique

Complex structures represent assemblages of distributed components such as beams, columns, etc. A method capable of modeling complex structures is the finite element method. The resulting discrete model generally possesses a large

number of degrees of freedom, and only a given number of lower modes can be computed accurately. This paper shows how to design a reduced-order controller to control a complex structure during earthquakes.

## DYNAMIC ENVIRONMENT

### ACOUSTIC EXCITATION

**83-1397**

**Ground Runup Noise Suppression Program. Part 3. Dry Suppressor Technology Base**

R. Glass and M. Lepor

Naval Ocean Systems Ctr., San Diego, CA, Rept. No. NOSC/TR-674, 205 pp (June 20, 1982) AD-A122 025

**Key Words:** Noise reduction, Experimental test data

The Ground Runup Noise Suppression Final Report consists of three documents. The first document is an executive summary which provides a brief, technical description and overview of the program conducted at the Naval Ocean Systems Center (NOSC). The second document provides a documented history of NOSC's participation in the Dry Jet Noise Suppression Program. This document is a technical summary of the information and data developed during the program. This report integrates predictive techniques, scale-model test results, and full-scale test results for the new air-cooled noise suppressor technology. All program data are summarized to assist the architect/engineer in the design of air-cooled noise suppressors.

**83-1398**

**Anti-Noise - The Essex Breakthrough**

B. Chaplin

Wolfson Centre for the Cancellation of Noise and Vibration, Univ. of Essex, Colchester, Essex, UK, Chartered Mech. Engr., 30 (1), pp 41-47 (Jan 1983) 19 figs, 8 refs

**Key Words:** Noise reduction

The principle of noise cancellation is based upon the addition of pure tone (sinusoid) to an antiphase version of equal amplitude. A method for generating the antiphase noise, called the waveform synthesis, is described.

**83-1399**

**Prediction of the Acoustic Intensity Based on Mode Shapes**

P. Sas and R. Snoeys

Kath. Univ. Leuven, Departement Werktuigkunde, Celestijnenlaan 300B, B-3030 Leuven, Belgium, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 403-409, 7 figs, 15 refs

**Key Words:** Sound intensity, Mode shapes, Modal analysis, Noise reduction

This contribution reports on research conducted in the field of noise control, especially the relation between modal deformations and radiated sound power. The reported technique fills in the gap between structural vibrations and radiated sound power. It enables, already in the design phase, accurate estimates of noise reduction measures.

**83-1400**

**Inter-Laboratory Variability of Sound Absorption Measurement**

R.E. Halliwell

Div. of Bldg. Res., National Res. Council of Canada, Ottawa, Ontario, Canada K1A 0R6, J. Acoust. Soc. Amer., 73 (3), pp 880-886 (Mar 1983) 8 figs, 3 tables, 15 refs

**Key Words:** Acoustic absorption, Test facilities, Measurement techniques

Sound absorption measurements have been made at a number of acoustical laboratories in Canada and the United States using the same specimen and the same measurement equipment and procedure. The results provide insight into the effect of reverberation room and diffuser geometry on measured absorption coefficients.

**83-1401**

**Estimation of Acoustic Velocity, Surface Velocity, and Radiation Efficiency by Use of the Two-Microphone Technique**

B. Forssen and M.J. Crocker

Ray W. Herrick Labs., School of Mech. Engrg., Purdue Univ., West Lafayette, IN 47907, J. Acoust. Soc. Amer., 73 (3), pp 1047-1053 (Mar 1983) 8 figs, 28 refs

**Key Words:** Acoustic intensity method, Measurement techniques, Two microphone technique

A theoretical derivation is presented for the spectral density of the acoustic velocity in terms of the auto- and cross-spectral densities of the signals from two closely spaced microphones. This result, together with a Fast Fourier Transform minicomputer and a two-microphone probe, was used to measure the surface velocity of a vibrating flat panel. The surface velocity thus measured agrees quite well, below the panel critical frequency, with that measured by an accelerometer. The two-microphone probe was then used to measure the acoustic intensity, and by summation, the acoustic power radiated by the same panel when it was acoustically and mechanically excited. The panel radiation efficiencies were calculated from these results for the acoustic and mechanical excitation cases. Satisfactory agreement was obtained with the theoretical panel radiation efficiency.

**83-1402**

**Acoustic Scattering by Elastic Solid Cylinders and Spheres in Viscous Fluids**

W.H. Lin and A.C. Raptis

Components Technology Div., Argonne Natl. Lab., Argonne, IL 60439, J. Acoust. Soc. Amer., 73 (3), pp 736-748 (Mar 1983) 8 figs, 4 tables, 40 refs

**Key Words:** Acoustic scattering, Cylinders, Spheres

This paper deals with analytic studies and numerical results of the scattering of plane sound waves from an elastic circular cylinder and from an elastic sphere in a viscous fluid. The elastic properties of the cylinder and the sphere and the viscosity of the surrounding fluid are taken into account in the solution of the acoustic-scattering problems. The associated acoustic quantities, such as the acoustic-scattering patterns, the acoustic-radiation forces, and the acoustic attenuation, are first derived in closed forms and then evaluated numerically for a given set of material properties. Numerical results show that increasing fluid viscosity tends to increase the directionality of the angular distribution of the scattering patterns, especially in the forward direction.

**83-1403**

**Acoustical Characteristics of Rigid Fibrous Absorbents and Granular Materials**

K. Attenborough

Engrg. Mechanics Discipline, Faculty of Technology, The Open Univ., Milton Keynes MK7 6AA, UK, J.

Acoust. Soc. Amer., 73 (3), pp 785-799 (Mar 1983)  
22 figs, 5 tables, 28 refs

**Key Words:** Soils, Acoustic properties

A model is developed that predicts the acoustical characteristics of rigid fibrous absorbent soils and sands from five parameters: porosity, flow resistivity, tortuosity, steady flow shape factor, and dynamic shape factor.

### 83-1404

#### **Geometric Dispersion of Acoustic Signals Propagated in a Deep Ocean Channel**

K.D. Flowers

Naval Res. Lab., Washington, DC 20375, J. Acoust. Soc. Amer., 73 (3), pp 806-809 (Mar 1983) 6 figs, 10 refs

**Key Words:** Underwater sound

Two sinusoidal signals generated in such a way as to have a constant frequency ratio are considered. Except for dispersive effects of the propagation channel, the two signal frequencies should remain correspondingly related at a distant receiver. As a measure of this relationship a correlation function is defined for signals of different frequencies. In general, it is concluded that the dispersive effects of the ocean channel at long range can be significant for broadband signals when signal coherence is an important consideration.

### 83-1405

#### **A Cautionary Note on the Use of Range-Dependent Propagation Models in Underwater Acoustics**

R.F. Henrick

The Johns Hopkins Univ., Applied Physics Lab., Johns Hopkins Rd., Laurel, MD 20707, J. Acoust. Soc. Amer., 73 (3), pp 810-812 (Mar 1983) 3 figs, 8 refs

**Key Words:** Underwater sound

A caution is given to the users of range-dependent models that utilize single ocean sound-speed profiles for discrete range intervals. It is shown that, if new profiles are not input every few kilometers, the effect of the discontinuities in the ocean may produce erroneous results. An example illustrates potential errors of as much as 18 dB using the Parabolic Equation Method to compute propagation through a Gulf Stream ring. It is argued that range interpolation routines

should be used to produce closely spaced profiles as a standard part of applying these acoustic propagation codes.

### 83-1406

#### **Optimum Frequency of Propagation in Shallow Water Environments**

F.B. Jensen and W.A. Kuperman

SACLANT ASW Res. Centre, 19026 La Spezia, Italy, J. Acoust. Soc. Amer., 73 (3), pp 813-819 (Mar 1983) 9 figs, 1 table, 23 refs

**Key Words:** Underwater sound

The optimum frequency of propagation in shallow-water environments is the result of competing propagation and attenuation mechanisms at high and low frequencies. It is shown that the optimum frequency is strongly dependent on water depth, that it has some dependence on the sound-speed profile, while it is only weakly dependent on the bottom type. A comparison between experimental data and normal-mode theory indicates the importance of shear waves in the bottom, both in determining the optimum frequency of propagation and in determining the actual propagation-loss levels at lower frequencies.

### 83-1407

#### **On the Calculation of Normal Mode Group Velocity and Attenuation**

R.A. Koch, C. Penland, P.J. Vidmar, and K.E. Hawker  
Appl. Res. Labs., The Univ. of Texas at Austin,  
Austin, TX 78712-8029, J. Acoust. Soc. Amer., 73  
(3), pp 820-825 (Mar 1983) 10 refs

**Key Words:** Underwater sound

The group velocity for a normal mode can be calculated without invoking a finite difference approximation requiring a second eigenmode calculation. The reciprocity relation is employed in a derivation of the normal mode group velocity and attenuation coefficient. The group velocity thus calculated is more accurate than a comparable finite difference approximation. Arbitrarily arranged layers of solid and fluid media are considered.

### 83-1408

#### **Transmission of a Pulsed Acoustic Signal at a Two-Fluid Interface**

J.N. Tjøtta and S. Tjøtta

Dept. of Mathematics, Univ. of Bergen, Bergen, Norway, J. Acoust. Soc. Amer., 73 (3), pp 826-834 (Mar 1983) 17 figs, 13 refs

**Key Words:** Underwater sound, Pulse excitation

The transmission of an acoustic pulse with a plane front at a two-fluid interface is considered. An exact solution is obtained and several properties are derived. Numerical examples are given, showing patterns of the transmitted signal for different pulse shapes and incident angles. It appears that penetration at angles above the critical incidence (according to Snell's Law) is possible, depending on how the incident pulse is shaped.

**83-1409**

**Response of Underwater Structures to Convective Component of Flow Noise**

K.L. Chandiramani

Bolt Beranek and Newman, Inc., 10 Moulton St., Cambridge, MA 02138, J. Acoust. Soc. Amer., 73 (3), pp 835-839 (Mar 1983) 6 figs, 5 refs

**Key Words:** Underwater structures, Plates, Sound transmission

Convective component of flow noise (for example, a turbulent boundary layer) is characterized by length scales of the order  $U/f$ , where  $U$  is the mean flow speed and  $f$  is the frequency. Nonresonant response of underwater structures to the convective component of flow noise is often of interest. An exact theory of transmission of sound across an isotropic flat plate, involving longitudinal and shear waves, is modified so as to apply at high, convective wavenumbers. Closed form results are presented.

## SHOCK EXCITATION

**83-1410**

**Analytic Model for Surface Ground Motion with Spall Induced by Underground Nuclear Tests**

D.H. MacQueen

Lawrence Livermore National Lab., CA, Rept. No. UCRL-53266, 36 pp (Apr 1982)  
DE82016783

**Key Words:** Underground explosions, Nuclear explosions, Sound generation

This report provides a detailed presentation and critique of a model used to characterize the surface ground motion following a contained, spelling underground nuclear explosion intended for calculation of the resulting atmospheric acoustic pulse. Some examples of its use are included. Some discussion of the general approach of ground motion model parameter extraction, not dependent on the specific model, is also presented.

**83-1411**

**Monotonic and Cyclic Constitutive Law for Concrete**

M.N. Fardis, B. Alibe, and J.L. Tassoulas

Massachusetts Inst. of Tech., Cambridge, MA, ASCE J. Engrg. Mech., 109 (2), pp 516-536 (Apr 1983)  
11 figs, 38 refs

**Key Words:** Concretes, Cyclic loading, Constitutive equations

A simple time-independent, mathematical model is proposed for the monotonic and cyclic behavior of concrete under multiaxial stress conditions.

**83-1412**

**Predictions of Collapse Modes in Crash-Impacted Structures Using a Finite-Element, Modal Energy, Approach**

K.J. Saczalski

Northern Arizona Univ., College of Engrg. and Tech., Flagstaff, AZ 86011, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 160-166, 7 figs, 2 tables, 8 refs

**Key Words:** Crashworthiness, Collision research (automotive), Crash research (aircraft), Modal analysis, Finite element technique

A modal technique employing linear system eigenvalues and eigenvectors, in conjunction with finite-element strain energy density distributions and average internal reaction loads, is utilized with empirically modified yield and buckling criteria to identify nonlinear collapse mode patterns in crash-impacted structural systems. This paper outlines the technique and compares results with preliminary investigations of crash-impacted frame type structures.

**83-1413**

**Protecting PCBs from Shock**

D.S. Steinberg

Mech. Engrg. Dept., Litton Guidance and Control Systems, Woodland Hills, CA, Mach. Des., 55 (5), pp 189-191 (Mar 10, 1983) 5 figs

**Key Words:** Circuit boards, Shock resistant design, Design techniques

A design procedure to reduce mechanical shock in electronic equipment is described. By designing the printed circuit boards to a resonant frequency one-half that of the chassis provides some isolation from shock induced vibration. Designing to this reverse octave rule keeps chassis vibration from being amplified. This technique also allows chassis mounting brackets to better withstand the small movements that occur with high chassis resonant frequency.

## VIBRATION EXCITATION

**83-1414**

**Dynamical Relation between Non-Conservative System and Fish Propulsion Mechanism**

T. Iwatsubo

The Faculty of Engrg., Kobe Univ., Rokko, Nada, Kobe, Japan, Bull. JSME, 26 (212), pp 283-290 (Feb 1983) 23 figs, 13 refs

**Key Words:** Self-excited vibrations, Energy conversion, Propulsion systems

This paper is concerned with the character of vibration after the self excited vibration has occurred and with the relation of energy conversion mechanism between the fish propulsion and the instability problems which occur in non-selfadjoint system. Block diagrams of these two behaviors are shown. The self excited vibration of a column subjected to tangential force, tubular cantilever conveying fluid, flutter of the wing, and oil whip of rotor system are investigated for eigenvalues, phase difference, and energy by means of two degree-of-freedom models. In the fish propulsion system, the vibration mode of a fish is analyzed from the viewpoint of phase angle between the deflection and attack angle. Then the relation of energy conversion and the vibration mode is discussed.

**83-1415**

**The Time-Distortion of Signal Due to the Periodical Fluctuation of Tape Velocity during Recording**

T. Žemaitis, A. Seilius, and A. Gražulevičius

Univ. of Vilnius, Vilnius, Lithuanian SSR, Vibrotechnika, 4 (34), pp 73-78 (1981) 4 refs  
(In Russian)

**Key Words:** Vibration measurement, Time-dependent parameters

The simple exact expressions of Fourier-coefficients of a signal and its phase-modulation, due to the arbitrary periodical fluctuation of tape velocity during recording, are obtained. The formulas contain no reverse functions. Several examples are illustrated.

## MECHANICAL PROPERTIES

### DAMPING

(Also see Nos. 1324, 1388)

**83-1416**

**Constrained Layer Damping as a Vibration and Noise Control Method**

B. Johansson

Antiphon AB, Sweden, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 87-108, 30 figs, 7 refs

**Key Words:** Layered damping, Vibration control, Noise reduction

Information is presented on the different damping techniques and the properties of damping materials showing how the modulus of elasticity, shear modulus, and loss factors are affected by temperature and frequency. Explanation is made of the properties of a constrained layer system and how the loss factor varies with unsymmetric and symmetric configurations and the thickness of the constrained layer compound.

**83-1417**

**The Use of Damping and Cancellation Devices to Reduce Punch Press Vibrations**

C. Stimpson

Univ. of Southampton, UK, Dynamic Vibration Isolation and Absorption Conf., Sept 8, 1982, Univ. of Southampton. Spons. Chartered Mechanical Engineer, Instn. of Mech. Engineers, pp 1-6, 7 figs, 3 refs

**Key Words:** Dampers, Semi-active isolation, Machine tools, Vibration control, Noise reduction

During a blanking or piercing operation on a power press, high levels of structural vibration can occur as the frame springs back following the very rapid release of strain energy as the work-piece material fractures. The ensuing transient vibration is a major source of noise and often leads to high rates of press wear. Smoothing the very rapid unloading of the structure is an effective form of noise control which can also give extended press life. The paper reviews current devices and reports on measurements made on a 25 ton C frame press and a 200 ton straight-sided press.

## FATIGUE

**83-1418**

### **Tank Car Head Shield Fatigue Evaluation**

W.F. Jackson and C.E. Anderson, Jr.

Ballistic Res. Lab., Army Armament Res. and Dev. Command, Aberdeen Proving Ground, MD, Rept. No. ARBRL-MR-03209, SBI-AD-F300 119, 44 pp (Nov 1982)  
AD-A121 606

**Key Words:** Fatigue tests, Railroad cars, Tank cars

An experimental program was performed to evaluate the fatigue damage sensitivity of a railroad tank car head shield, required by federal regulation HM-144 in the transport of certain hazardous materials. The test procedures and data collected are documented. Analysis of the data obtained from these tests showed that currently applicable head shield specifications were met.

## ELASTICITY AND PLASTICITY

**83-1419**

### **Dynamic Mechanical Analysis Assures Composite Quality**

P.S. Gill

Clinical & Instrument Systems Div., DuPont Co., Wilmington, DE, Indus. Res. & Dev., 25 (3), pp 104-107 (Mar 1983) 3 figs, 6 refs

**Key Words:** Composite materials, Viscoelastic properties, Time-dependent parameters, Temperature effects, Variable material properties

A dynamic mechanical analysis procedure, which measures the viscoelastic properties (modulus and damping) of a material as a function of time and temperature, is considered for application in several types of composites. They include classical glass/epoxy systems (cured and uncured), continuous-filament graphite/epoxy advanced composites (cured and uncured), aramid-fabric-reinforced epoxy, and a chopped-glass-reinforced thermoplastic polyester.

**83-1420**

### **On Path-Independent Integrals and Fracture Criteria in Non-Linear Fracture Dynamics**

C. Ouyang

Dept. of Mathematics, Fudan Univ., Shanghai, China, Intl. J. Nonlin. Mech., 18 (1), pp 79-86 (1983) 5 figs, 3 refs

**Key Words:** Fracture properties

A new path-independent integral for nonlinear fracture dynamics is proposed. First the elastic case is examined, then the elasto-plastic case. A relation between the new integral and the crack extension force in fracture dynamics is presented.

**83-1421**

### **Numerical Problems of Nonlinear Stability Analysis of Elastic Structures**

Z. Waszczyszyn

Technical Univ. of Cracow, ul. Warszawska 24, 31-455 Krakow, Poland, Computers Struc., 17 (1), pp 13-24 (1983) 11 figs, 45 refs

**Key Words:** Stability, Elastic systems, Finite element technique

Basic definitions and relations for stability of elastic discrete systems under one-parameter conservative loads are briefly presented. On the basis of the potential energy function the incremental FEM equations are derived. Various methods of computation of paths of equilibrium are discussed. Different stability criteria for computation of critical points are discussed. Tracing of a postbifurcation path of equilibrium is pointed out.

# EXPERIMENTATION

## MEASUREMENT AND ANALYSIS

(Also see Nos. 1281, 1296, 1297, 1298, 1313, 1314, 1315, 1317, 1401, 1419, 1460, 1462, 1463, 1464, 1481, 1496)

**83-1422**

### **Interferometric Phase Calibration of Vibration Pickups**

M.R. Serbyn

National Bureau of Standards, Washington, D.C. 20234, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 223-229, 7 figs, 7 refs

**Key Words:** Vibration measurement, Measuring instruments, Accelerometers, Sensitivity analysis, Calibrating

An absolute method for measuring the phase component of pickup sensitivity is described. The phase calibration is in terms of the time interval between zero crossings and can be performed along with magnitude calibration on an automated Michelson interferometer. The procedure is simplest when the peak vibrational displacement is between about 30 and 120 nm.

**83-1423**

### **The Use of Back-to-Back Accelerometers as Precision Vibration Standards**

B.F. Payne

National Bureau of Standards, Washington, D.C. 20234, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 212-215, 7 figs, 2 refs

**Key Words:** Accelerometers, Vibration measurement, Measuring instruments, Calibrating

Precision vibration measurements depend on accurate and repeatable calibration methods. Standardization of calibration test equipment and measurement techniques ensures more accurate and repeatable measurements. The use of back-to-back accelerometers as laboratory standards has become widespread. However, this use has been somewhat limited because of inadequate calibration methods. Recent developments in improved calibration methods has given

the back-to-back accelerometer a greater potential as an accurate, repeatable, and stable vibration standard. Recent work in this area is presented along with a description of a typical back-to-back transducer calibration.

**83-1424**

### **A New Frequency for Piezoelectric Resonator Measurement**

W.H. Horton and R.C. Smythe

IEEE, Proc., 71 (2), pp 280-282 (Feb 1983) 2 figs, 7 refs

**Key Words:** Piezoelectric transducers, Resonators, Vibration measurement, Measuring instruments

A new frequency associated with the reflection coefficient of a piezoelectric resonator is described which is independent of the length of the uniform transmission line connecting the resonator with the measurement system. The frequency is also independent of the resonator motional resistance and has other properties which make it potentially useful for special measurement purposes.

**83-1425**

### **Multicomponent Dynamometers Using Quartz Crystals as Sensing Elements**

K.H. Martini

Kistler Instrumente AG, Switzerland, ISA, Trans., 22 (1), pp 35-46 (1983) 11 figs, 21 refs

**Key Words:** Dynamometers, Quartz crystals, Transducers

The unique characteristics of quartz crystal make it possible to resolve any force acting on a quartz sensing element (3-component transducer) into three orthogonal components directly. A multicomponent dynamometer is usually composed of typically four elements that are sandwiched between two plates. Forces and moments are obtained by adding and subtracting individual force components measured by the sensing elements involved. By evaluating the individual force outputs it is also possible under certain conditions to calculate the coordinates of the point of force application and the free movement (torque) around a vertical axis. The main characteristics of quartz and strain gage dynamometers are compared; advantages and disadvantages are discussed. Reference is made to successful applications, and respective publications are cited.

**83-1426**

**The Digital Approach to Engineering Measurement - Part 1**

P. Colwill and M. Caudell

Data Laboratories Ltd., Chartered Mech. Engr., 30  
(3), pp 51-52 (Mar 1983) 4 figs

**Key Words:** Measuring instruments, Computer-aided techniques, Digital techniques

This article aims to present the capability of the transient waveform recorder in mechanical engineering measurement. The first part examines the instrument's main features, with special attention to its connection with a computer via an interface; the second part discusses the digital measurement of physical signals and easy-to-use measurement systems based upon the transient waveform recorder, and concludes with a look at some of the applications of the instrument.

**83-1427**

**A Correlation Coefficient for Modal Vector Analysis**

R.J. Allemang and D.L. Brown

Mech. and Industrial Engrg., Univ. of Cincinnati, Cincinnati, OH 45221, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 110-116, 11 refs

**Key Words:** Modal analysis, Correlation techniques

Multiple, independent modal vector estimates may be generated whenever multiple rows or columns of the frequency response function matrix are available. These independent estimates of the same modal vector need to be processed into a single best estimate of that particular modal vector. The development of the concept of consistency of modal vectors, evaluated through the use of the modal assurance and modal scale factor, is useful in computing a best estimate of the modal vector and useful in understanding the errors among separate estimates of the same modal vector.

**83-1428**

**Modal Analysis - Past, Present and Future**

D.L. Brown

Univ. of Cincinnati, Cincinnati, OH, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando,

FL. Spons. Union College, Schenectady, NY, pp ix-xiii

**Key Words:** Modal analysis, Reviews

This paper is brief review of the material which was covered in the keynote speech given at the first International Modal Analysis Conference held at Orlando, Florida, November 8-10, 1982.

**83-1429**

**Impulse Testing Validation of a Mathematical Model**

J.H. Bond

Corporate Consulting and Development Co., Ltd., Raleigh, NC, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 238-244, 5 figs, 2 tables, 8 refs

**Key Words:** Impulse testing, Testing techniques, Natural frequencies, Mode shapes

Impulse testing is a means by which natural frequencies and mode shapes can be determined experimentally. The process involves determining the transfer function, or the ratio of a measured response of a structure to a specific input in the frequency domain. Natural frequencies and mode shapes can be scaled from the transfer function results. When impulse testing was used to validate a mathematical analysis of a cantilever beam, results showed that the rigid boundary condition used in the mathematical model was stiffer than the experimental results indicated. By relaxing the boundary condition in the mathematical model of the structural problem, the analytically determined frequencies and mode shapes were found to correspond with the experimentally determined results.

**83-1430**

**An Algorithm for Hidden Line Estimation of Oblique Projection**

J. Sato

Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 118-122, 2 refs

**Key Words:** Modal analysis, Algorithms

An effective algorithm for outline detection, drawing and hidden line elimination of three-dimensional objects using an XY-plot is dealt with in this paper. Illustrative examples are given along with results of the oblique projection.

**83-1431**

**Basic Consideration of Experimental Modal Analysis**

N. Okubo and S. Honda

Chuo Univ., Tokyo, Japan, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 130-135, 16 figs, 6 refs

**Key Words:** Modal analysis, Impact tests

For the application of impact excitation to a mechanical structure which has a nonlinear element, a numerical simulation based on mathematical models and also a test of dynamic behavior of the structure, are carried out to analyze the frequency response function. A discussion is made on current techniques for the extraction of natural frequency damping ratio from measured data and necessary considerations to improve them are given.

**83-1432**

**On the Determination and Use of Residual Flexibilities, Inertia Restraints, and Rigid-Body Modes**

M.A. Lamontia

E.I. DuPont de Nemours & Co., Inc., Wilmington, DE, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 153-159, 9 figs, 3 refs

**Key Words:** Model analysis, Residual flexibility effects, Inertia restraints, Rigid-body modes

For some structures, model analysis by itself is inadequate for creating a structural model. Rather, high-frequency residual flexibility effects and low-frequency inertia restraints or the equivalent rigid-body modes must be found. The importance of these residual effects is demonstrated with real structures. Methods of computing the terms for both symmetric and asymmetric structures are outlined.

**83-1433**

**Dynamic Measurements on and with Non-Linear Systems: Problems and Approaches**

P.K. Stein

Stein Engineering Services, Inc., Phoenix, AZ, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 358-389, 23 figs, 31 refs

**Key Words:** Modal analysis, Time-dependent parameters, Nonlinear systems

Whenever the relationship between two quantities is anything other than a straight line, time variations of one quantity at one set of frequencies will result in time variations of the other quantity at a different set of frequencies. Nonlinear systems are frequency-creative. Some of the consequences of the frequency-creative ability of nonlinear systems on the design of measuring systems will be developed in this paper and supported by examples.

**83-1434**

**An Inexpensive, Microcomputer-Based, Modal Analysis and Testing System**

M.S. Darlow, E. Willstaedt, and S.A. Marquiss

Dept. of Mech. Engrg., Aeronautical Engrg. and Mechanics, Rensselaer Polytechnic Inst., Troy, NY, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 245-251, 3 figs, 19 refs

**Key Words:** Modal analysis, Impulse testing, Finite element technique

An integrated modal analysis and testing system is described in this paper. This system is built around a personal microcomputer and is relatively inexpensive. The computer is capable of performing sophisticated analysis with substantial quantities of data. Of particular interest here are an interactive finite element analysis package and a general transfer matrix analysis package.

**83-1435**

**Combining Analytical and Experimental Modal Analysis for Effective Structural Dynamical Modeling**

T.G. Pal and R.A. Schmidtberg

Nicolet Scientific Corp., Northvale, NJ, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 265-271, 3 figs, 2 refs

**Key Words:** Modal analysis, Finite element technique

This paper reviews the basic principles of both analytical and experimental modal analysis, highlighting the strengths and weaknesses of each technique. Some guidelines for selecting the appropriate analysis procedure are also pre-

sented. Examples are offered from a recently developed mini-computer system, which provides both experimental and analytical (finite element method) modal analysis capabilities.

**83-1436**

**Global Fitting, an Efficient Method of Experimental Modal Analysis of Mechanical Systems**

J.G. Gimenez and L.I. Carrascosa

Escuela Tecnica Superior de Ingenieros Industriales, Universidad de Navarra, San Sebastian, Spain, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 528-533, 5 figs, 1 table, 7 refs

**Key Words:** Modal analysis, Global fitting method, Viscous damping

A method is proposed for the experimental modal analysis of mechanical systems based on the simultaneous treatment of all available transfer functions. Although this method may be used for other types of damping, it has been codified under the hypothesis of non-proportional viscous damping with complex natural modes of vibration. It is based on the theoretical curve fitting of the experimental transfer function. The authors describe various applications to practical problems where other methods have shown serious limitations.

**83-1437**

**Dynamics of Periodic Structures by Means of Transfer Matrices**

H. Pastorel, M. Massoud, and J.G. Beliveau

Mark Hot Industries, Longueuil, Quebec, Canada, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 489-494, 6 figs, 1 table, 12 refs

**Key Words:** Periodic structures, Transfer matrix method, Resonant frequencies, Mode shapes

Dynamic characteristics of periodic (repetitive) structures, may be obtained from their transfer matrices. In this paper, these matrices are calculated without successive multiplication of identical elementary transfer matrices of substructure or the calculation of their eigenvalues and eigenvectors. The analysis allows the effects of external forces and moments acting on the structure to be included. The procedure requires less memory and allows greater accuracy in the results than existing procedures.

**83-1438**

**Seismic Qualification Using Digital Signal Processing/Modal Testing and Finite Element Techniques**

J.B. Steedman and A. Edelstein

Structural Dynamica Lab., Fullerton, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 622-629, 5 figs, 2 tables

**Key Words:** Equipment response, Signal processing techniques, Modal tests, Finite element technique, Seismic analysis

A systematic procedure in which digital signal processing, modal testing and finite element techniques can be used to seismically qualify Class 1E equipment for use in nuclear generating stations is presented. A new method was also developed, in which measured transmissibility functions and Fourier transformation techniques were combined to compute instrument response spectra.

**83-1439**

**A New Complex Exponential Frequency Domain Technique for Analyzing Dynamic Response Data**

L.W. Schmerr

Dept. of Engrg. Science and Mechanics and the Engrg. Res. Inst., Iowa State Univ., Ames, IA 50011, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 183-186, 12 refs

**Key Words:** Frequency domain method, Time domain method, Vibration tests, Testing techniques, Modal analysis

Accurate measurements of the dynamic characteristics of structures and materials are becoming increasingly important in modern analysis and design procedures. A crucial factor in the use of such measurements is the ability to obtain important physical parameters such as natural frequencies, damping values, etc. directly from the dynamic test data. Recently, two new methods, Ibrahim's Time Domain Modal Identification Algorithm and the Single-Station Time-Domain Vibration Testing Technique, have proven to be particularly successful in extracting the natural frequencies and associated damping ratios from the free vibration time response of a structure. This paper describes the development of a frequency-domain version of these methods, which may have certain advantages with respect to sampling and filtering over the time-domain algorithms, and its use for a simple system.

**83-1440**

**Finite Element Model Validation Via Modal Testing**

J.B. Stimpson and D.T. Griffith

Raytheon Co., Portsmouth, RI, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 456-461, 8 figs, 3 tables

**Key Words:** Modal analysis, Modal tests, Finite element technique

Finite element analysis can be an extremely effective design tool once a valid model of the structure is obtained. An experimentally validated model increases the confidence level in the analysis of proposed design changes. This paper shows how modal testing was used to improve the accuracy of a finite element model in predicting the resonant frequencies and corresponding mode shapes of a test fixture. Two different mounting configurations were studied.

### 83-1441

#### **Experimental Modal Analysis, Structural Modifications and FEM Analysis - Combining Forces on a Desktop Computer**

K.A. Ramsey and A. Firmin

Structural Measurement Systems, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 443-455, 13 figs, 2 tables, 4 refs

**Key Words:** Modal analysis, Modal tests, Finite element technique, Mode modification method

This paper discusses structural dynamics technology in terms of its two most important parts; the experimental portion and the analytical portion. It discusses how experimental and analytical methods are used to solve noise and vibration problems and how they may be used together for even greater benefit. It also shows how structural modification techniques are used as a complement to both methods and how all of the tools may be combined on an inexpensive desktop computer. The paper concludes with an example showing how experimental modal analysis, structural dynamics modification and finite element analysis were used to analyze a test structure.

### 83-1442

#### **An Efficient Method for Predicting the Dynamic Effects of Redesign**

M.N. Rizai and J.E. Bernard

Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10,

1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 436-442, 4 figs, 10 refs

**Key Words:** Mode modification method, Finite element technique

A method is presented for predicting the effect of design changes on system eigenvalues. The method uses a finite element preprocessor to find derivatives of the mass and stiffness matrices, and computationally efficient techniques to find eigenvector derivatives. Example problems illustrate the strength and limitations of the technique.

### 83-1443

#### **Modal Control of Vibrating Systems**

A.N. Andry, Jr., E.Y. Shapiro, and J.C. Chung

Lockheed California Co., Burbank, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 430-435, 10 refs

**Key Words:** Mode modification method, Active control

An active eigenstructure modification method and the theory behind it is described. Basically, the method utilizes the response of the system in feedback in order to modify the eigenvalues and eigenvectors of the system.

### 83-1444

#### **System Modeling and Modification Via Modal Analysis**

Y.W. Luk

Zonic Corp., Milford, OH 45150, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 423-429, 1 table, 18 refs

**Key Words:** Modal analysis, Mode modification method

This paper deals with the different ways of modifying a prototype structure analytically. This modified model is used to predict the new dynamic characteristics of the modified structure resulting from changes in its mass, stiffness, or damping properties. There are three ways that modifications can be made: in the physical coordinates model; in both the physical and modal coordinates models; and in the modal coordinates model.

83-1445

**A Structural Modification Procedure Using Complex Modes**

J. O'Callahan and P. Avitabile

Univ. of Lowell, Lowell, Massachusetts, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 418-422, 1 fig, 7 refs

**Key Words:** Mode modification method, Modal tests, Experimental test data, Finite element technique

A general procedure is presented that performs structural modifications of modal data from either a finite element analysis using the undamped or damped (complex) modal data or using modal data obtained from an experimental modal analysis. With this modal data, a projection of physical changes of mass, damping, and stiffness matrices are formed in modal coordinates. A complex eigensolution is performed to extract the modal matrix that reflects the system physical changes.

83-1446

**A Study of Impulse Excitation and the Modal Parameters Identification for Mechanical Structure**

Yongfang Zhou, Yueming Sun, Naiyan Lu, Yaodong Cheng, and Zhongfang Tong  
Zhejiang Univ., Hangzhou, Zhejiang, China, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 350-357, 12 figs, 3 refs

**Key Words:** Modal analysis, Impulse testing, Parameter identification technique

A procedure consisting of impulse excitation and identification of structural modal parameters is presented. Through Fast Fourier Transform of force and response signals, cross-spectral and auto-spectral density can be obtained and the ratio shows the transfer function.

**DYNAMIC TESTS**

(Also see No. 1316)

83-1447

**Transient Response of a Central Crack to a Tensile Pulse**

A.A. Sukere and W.N. Sharpe, Jr.

Univ. of Missouri-Columbia/Kansas City, Independence, MO 64050, Exptl. Mech., 23 (1), pp 89-98 (Mar 1983) 10 figs, 27 refs

**Key Words:** Cracked media, Transient response, Pulse excitation, Plates, Impact tests, Interferometric techniques, Testing techniques

This experimental investigation studies the opening displacement of a central electromachined slot in a thin aluminum plate subjected to an elastic tensile pulse. The tensile pulse was generated by an impact apparatus, and in-plane displacements were measured by interferometric techniques. Comparison with existing analytical and finite-element solutions was good for short times.

83-1448

**Dynamic Wheel-Testing Rig (Fahrdynamischer Räderprüfstand)**

S. Angerer and H. Naundorf

Automobiltech. Z., 85 (2), pp 71-76 (Feb 1983) 8 figs, 14 refs  
(In German)

**Key Words:** Dynamic tests, Test facilities, Wheels, Vehicle wheels

The dynamic wheel-testing rig developed by BMW has been designed in such a way as to reproduce actual road conditions, thus making it possible to simulate in the laboratory the complex stresses involved. The article gives an account of the development and construction of the test rig.

83-1449

**Airfoil Vibration Test Apparatus**

C.B. Jones

Dept. of the Air Force, Washington, D.C., U.S. Patent 4-350 043, 7 pp (Sept 1982)

**Key Words:** Test equipment and instrumentation, Vibration tests

This patent describes an apparatus for inducing high frequency out-of-phase, vibrations in adjacent span-wise panel portions of a plate type structure, such as an airfoil blade of a gas turbine engine. The apparatus includes a novel bifurcated duct for conducting and directing two out-of-phase streams of gaseous flow, and a uniquely structured air chopper which generates the two out-of-phase gaseous streams.

**83-1450**

**Vibrational Modes of Plates and Cymbals**

T.D. Rossing, R.B. Shepherd, R.W. Peterson, and C.A. Anderson

Northern Illinois Univ., DeKalb, IL, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 88-94, 12 figs, 1 table, 3 refs

**Key Words:** Musical instruments, Vibration tests, Testing techniques

A study is made of the vibrational modes of percussion musical instruments by several techniques, including Chladni patterns, time-averaging holographic interferometry, digital modal analysis, and direct probing of the near-field sound with a microphone. These techniques are described, and examples are given of their application to circular plates and cymbals.

**83-1451**

**Dynamic Analysis Techniques for Aluminum-Filled Epoxy Models**

W.R. Shapton and R.N. Lund

Michigan Technological Univ., Houghton, MI 49931, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 208-211, 4 figs, 1 table

**Key Words:** Testing techniques, Modal analysis, Test models

This paper discusses the use of aluminum-filled epoxy structural models for dynamic modal analysis. Model ease of preparation and evaluation indicate that aluminum-filled epoxy can be extended from static stress analysis to dynamic analysis. Test procedures are investigated and results are discussed.

**83-1452**

**The Dynamic Characteristics of a New Hydraulic Vibrator**

Jiaqiang Pan, Yaodong Cheng, Zhongfang Tong, and Yueming Sun

Zhejiang Univ., Hangzhou, Zhejiang, China, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 230-237, 11 figs, 4 refs

**Key Words:** Vibration tests, Test facilities, Hydraulic systems, Vibrators (machinery), Machine tools

The dynamic characteristics of a simple new hydraulic vibrator are investigated theoretically and experimentally. The main transfer functions of the vibrator; i.e., source impedances and force transmissibility, and energy relationships are derived. Theoretical calculations are compared with experimental results.

**83-1453**

**Random Vibration Testing of a Single Test Item with a Multiple Input Control System**

D.O. Smallwood

Sandia National Labs., Albuquerque, NM, Rept. No. SAND-81-2011C, CONF-820411-1, 8 pp (1981) DE82005687

**Key Words:** Random vibration, Vibration tests, Shakers, Control equipment, Algorithms

This paper develops an algorithm for a multiple shaker random vibration control system. The system is designed for several shakers driving a single test item with full cross-coupling control. The method allows for cross-coupled mechanical systems with partially coherent control points.

**83-1454**

**Random Vibration Control System for Testing a Single Test Item with Multiple Inputs**

D.O. Smallwood

Sandia National Labs., Albuquerque, NM, Rept. No. SAND-82-1631C, CONF-821019-1, 7 pp (1982) DE82018973

**Key Words:** Random vibration, Vibration tests, Shakers, Control equipment

This paper describes a multiple shaker control system developed for driving a single test item with random excitation. The system allows for cross-coupled mechanical systems with partially coherent control points. The system uses time-domain randomization to generate the continuous Gaussian drive signals.

**83-1455**

**A Generalized Approach to the Transient Response of Servovalve Controlled Asymmetric Actuators and Its Practical Realization**

J. Watton  
University College, Cardiff, Wales, ASME Paper No.  
82-WA/DSC-8

**Key Words:** Test equipment and instrumentation, Transient response, Fatigue life, Ground vehicles, Aircraft

The transient performance of a servovalve controlled asymmetric actuator of the type used for fatigue testing of vehicle and airframe systems is assessed both analytically and experimentally.

## SCALING AND MODELING

### 83-1456 Model Studies of Acoustic Propagation over Finite Impedance Ground

D.A. Hutchins, H.W. Jones, and L.T. Russell  
Physics Dept., Dalhousie Univ., Halifax, Nova Scotia, Canada, *Acustica*, 52 (3), pp 169-178 (Feb 1983)  
18 figs, 18 refs

**Key Words:** Scaling, Elastic waves, Sound propagation, Acoustic impedance

A scale modeling technique is described, which is capable of predicting sound levels following propagation over flat ground of finite impedance. Experimental model data has been compared favorably to both outdoor measurements, obtained in a neutral atmosphere or at short ranges, and to theory with flow resistivity as the parameter.

## DIAGNOSTICS

### 83-1457 Troubleshooting In-Plant Equipment Using Combined Test and Analysis

G.F. Mutch and R. Russell  
GE CAE International, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 252-258, 18 figs, 1 ref

**Key Words:** Diagnostic techniques, Modal tests, Industrial facilities, Equipment response

This paper describes new modal test methods that are useful in obtaining a modal model with accuracy suitable for analytical work. Techniques to verify that the modal model accurately represents the test item are reviewed. Also described are the analytical methods that directly use the test data. A case history is presented documenting the application of the suggested methods to solving a severe vibration problem in a large process machine. Initial test results, analytical modifications and correlation of analysis with the modified system are given.

## BALANCING

### 83-1458 Does a Microprocessor System Help in a Universal Balancing Machine? (Nützt ein Mikroprozessor-System bei einer Universal auswuchtmaschine?)

H. Schneider  
*Feinwerktechnik & Messtechnik*, 91 (1), pp 25-27 (1983) 6 figs, 1 table  
(In German)

**Key Words:** Balancing machines, Microprocessors (computers)

A detailed look into the tasks of a universal balancing machine shows that the use of a microprocessor system can be purposeful if the specific situation and the required dialogue between the operator and the measuring device are accounted for. Operating and display elements are also investigated.

## MONITORING

### 83-1459 Measurement of Ball Bearing Vibrations

L. Geller  
*Vibrotechnika*, 4 (34), pp 7-11 (1981) 6 refs  
(In Russian)

**Key Words:** Bearings, Ball bearings, Diagnostic techniques

A method for the control of low frequency vibration of small ball bearings is described. It is shown that ball bearing quality can be determined from its vibration characteristics by measuring the rectification signal of vibration velocity.

# ANALYSIS AND DESIGN

## ANALYTICAL METHODS

83-1460

### Method of Quantifying the Accuracy of Modal Truncation in Three-Dimensional Seismic Analyses

T.H. Lee

General Atomic Co., P.O. Box 81608, San Diego, CA 92138, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 636-642, 2 figs, 1 table, 11 refs

**Key Words:** Seismic analysis, Modal truncation

A method is presented for assessing the deviations in response values of a dynamic system determined by a truncated-mode solution as compared to those given by an all-mode solution. The technique was developed by first deriving the matrix equation which serves as a quantitative measure for the accuracy of the truncated analysis. From the properties of this measure, correction schemes can be developed to improve the accuracy of a dynamic solution using lower modes only. Application of the method is illustrated by considering a three-dimensional seismic analysis.

83-1461

### Solution of a General Eigenvalue Problem by Singular Value Analysis

F.R. Bourne and M.W. Dixon

Mech. Engrg. Dept., Clemson Univ., Clemson, SC 29631, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 141-146, 4 figs, 1 table, 14 refs

**Key Words:** Eigenvalue problems, Beams, Elastic foundations, Free vibration

A technique that may be used to solve the eigenvalue problem  $\underline{A}(\lambda)\underline{x} = \underline{Q}$  is presented. The technique involves computing the singular value decomposition of  $\underline{A}(\lambda)$  to determine when  $\underline{A}(\lambda)$  is singular. It is shown that by using this method, the eigenvectors are easily recovered. The technique is applied to the free vibration analysis of a continuous beam supported by elastic elements placed at periodic

intervals. Results are shown to correspond closely with previous findings.

83-1462

### Modal Analysis for Asymmetric Systems

D.J. Inman

Dept. of Mech. and Aerospace Engrg., State Univ. of New York at Buffalo, Buffalo, NY 14260, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 705-708, 5 refs

**Key Words:** Modal analysis, Linear systems, Asymmetry, Viscous damping, Gyroscopic effects

A method of factoring asymmetric matrices into the product of two symmetric matrices is exploited to provide a modal analysis technique for a certain subclass of asymmetric linear dynamic systems. This subclass consists of systems whose coefficient matrices have real eigenvalues, but are not necessarily symmetric. The method is first presented for systems without velocity dependent forces. The technique is then extended to include systems subject to viscous damping and gyroscopic forces. An example is presented illustrating the details of the method.

83-1463

### Comparison of Finite Element and Experimental Modal Analyses of a Complex Structure

F.S. Heming, Jr. and B.J. Simmons

Dept. of Engrg. Mechanics, USAF Academy, CO 80840, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 603-607, 14 figs, 3 refs

**Key Words:** Modal analysis, Modal tests, Finite element technique

The development of a sub-seismically quiet platform for testing higher precision gyros and accelerometers provided the impetus for a comparison of experimental and finite element modal analysis techniques on a complex structure. To gain confidence in predicting performance of new platform designs, a comparison of experimental and finite element results was made of modal analyses of an existing instrument test platform. This paper summarizes the techniques, models, and results used for the comparison. The comparison illustrates the accuracy and design value of the experimental and finite element techniques used and how

design confidence can be enhanced prior to a major commitment in fabrication expense.

### 83-1464

#### **Accuracy of Modal Approximations for Dynamic Response Analysis of Non-Proportionally Damped Mechanical Structures**

H.N. Ozguven and S.E. Semercigil

Middle East Technical Univ., Ankara, Turkey, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 662-670, 9 figs, 4 tables, 21 refs

**Key Words:** Modal analysis, Damped structures, Mode superposition method

Non-proportional damping does not allow the classical mode superposition for the determination of the dynamic response of structures, and necessitates more time consuming and complex computation techniques to be used. In order to avoid the expense of these solution techniques, different approximate methods have been proposed. The most popular of these is the uncoupled mode superposition method. The single mode method has recently been suggested as an alternative and tested for simple discrete systems. In this paper, the accuracy of the single mode method when used for the dynamic response analysis of structures is investigated by analyzing clamped-clamped and clamped-free beams with varying amounts and distribution of damping.

### 83-1465

#### **The Application of Substructuring Methods to Acoustic Finite Element Analysis**

R.J. Bernhard and D.K. Holger

Ray W. Herrick Labs., School of Mech. Engrg., Purdue Univ., West Lafayette, IN 47907, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 514-519, 3 figs, 3 tables, 12 refs

**Key Words:** Substructuring methods, Sound propagation, Finite element technique

Finite element analysis has been successfully applied to a wide variety of acoustic propagation problems. However, the economics of the method makes it unsuitable for many problems that are of practical interest. Substructuring techniques can improve the efficiency of the finite element method in such cases. The accuracy, convergence and effi-

ciency of the finite element method using substructuring techniques is discussed for acoustic problems. The method is applied to a problem involving a repeated geometry and to a parameter study. The cases studied indicate that the method is accurate and practical and also illustrate the use of superelements for design studies. A technique is proposed for integrating the methods discussed into optimal design algorithms.

### 83-1466

#### **Load Cell Technique for Coupling Separate Structural Simulations**

G.D. Shepard

Univ. of Lowell, Lowell, MA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 508-513, 7 figs, 2 tables, 2 refs

**Key Words:** Substructuring methods

Structural dynamic models of large space structures often must account for significant nonlinear effects such as gyroscopic and centrifugal forces, configuration dependent mass and stiffness matrices, and nonlinear constitutive relations for control components. The solution of the nonlinear system equations must proceed by computer simulation. It is often necessary to couple existing separate dynamic simulations. By introducing a hypothetical load cell at the interface, reactions proportional to the lack of compatibility can be generated. The reactions then act to reduce the incompatibility to acceptable limits. The addition of a load cell has the undesirable side effect of causing extra vibration modes which are localized at the interface region. These modes may adversely affect the cost, stability and fidelity of the simulation. Using a root locus technique, two strategies for reducing the adverse side effects of the load cell are examined. A simulation example which models a rigid interface between two beams shows the feasibility of the load cell technique.

### 83-1467

#### **A Family of Subspace Iteration Algorithms for the Eigensolution of Large Structural Systems Composed of Substructures**

A.L. Hale

Aeronautical and Astronautical Engrg. Dept., Univ. of Illinois at Urbana, IL, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 500-507, 21 refs

**Key Words:** Eigenvalue problems, Substructuring methods

Subspace iteration is a direct iterative method for producing the partial eigensolution of large structural systems. The classical subspace iteration method is a combination of a Rayleigh-Ritz order reduction and simultaneous matrix iteration for the whole structure. This paper is concerned with a family of subspace iteration algorithms that extend the classical method and that are based on a division of the whole structure into substructures. Multiple levels of substructures are considered.

**83-1468**

**Complex Mode Extraction by a Conjugate Subspace Inverse Power Method**

J. O'Callahan and C. Finch

Univ. of Lowell, Lowell, MA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 495-499, 1 table, 2 refs

**Key Words:** Eigenvalue problems

A complex eigensolution of a structural system is accomplished by a method using a conjugate subspace, containing a trial mode vector and a pseudo conjugate vector. These vectors are used to project physical information into modal space. An inverse power method is then used to extract the dominant eigenvalue and its corresponding eigenvector from the conjugate subspace. Once the dominant eigenpair has been obtained, a Gram Schmidt orthogonalization process is used to purge the effects of the eigenpair (and its conjugate) from the system equations. Additional eigenpairs can then be extracted. An advantage of this technique is that any number of eigenpairs can be obtained.

**83-1469**

**Correlation of Experimental and Analytical Structural Dynamics Parameters -- A 1982 Overview**

M.P. Pakstys

Electric Boat Div., General Dynamics, Groton, CT, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 59-65, 3 figs, 2 tables, 17 refs

**Key Words:** Correlation technique, Experimental test data, Finite element technique, Reviews

The techniques being used to correlate experimentally derived structural dynamics parameters predicted by use of finite element models are reviewed. Criteria for success of correlation of the test and analysis data are discussed. The structural dynamics parameters which are directly related to structural integrity are emphasized. The increased complexities of transient response are discussed.

**83-1470**

**System Prediction Using Reduced Component Modes**

K.F. Martin and K.H. Ghilaim

Univ. of Wales Inst. of Science and Tech., Cardiff, Wales, UK, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 520-525, 3 figs, 2 tables, 11 refs

**Key Words:** Component mode synthesis, Natural frequencies, Low frequencies

This paper describes a component mode method, with reduction, to find the lower natural frequencies of a system. The method applies where the connections can be characterized by stiffness and damping. A matrix set involving the eigenvalues and eigenvectors of the components together with a connection matrix is solved to give eigensolutions of the system; reduction is affected by approximating the components by a reduced set of eigenvalues and an equally reduced set of displacements in the eigenvector.

**83-1471**

**Impact Modal Pseudoforce Technique for Nonlinear Dynamic Analysis**

M.J. Yan and R.E. Clark

Babcock and Wilcox, Lynchburg, VA, ASME Paper No. 82-WA/PVP-7

**Key Words:** Modal superposition method

It is shown by example cases that the technique of modal superposition and modal pseudoforce based on impact theory calculates accurate results for the gap and linear dynamic structures. Results obtained with this technique compare very well with a theoretical solution and with solutions from another code.

83-1472

**Assembling Large Scale System Models from Test and Analysis Using Interactive Computing**

J. Klahs, M. Goldstein, R. Madabusi, and R. Russell  
Structural Dynamics Res. Corp., Milford, OH, Intl. Modal Analysis Conf., Proc. 1st, Nov. 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 46-52, 8 figs, 3 refs

**Key Words:** Component mode synthesis, Computer-aided technique

The advent of the super-mini computer has brought computing power closer to the working engineer and made interactive capabilities more feasible. This paper discusses the implementation of system analysis capabilities in an interactive environment. Graphically oriented methods for data entry, verification and results interpretation are presented. Solution methods oriented toward the super-mini computer are also discussed. The potential impact of these new methods on the design process is reviewed.

83-1473

**A Study of Nonlinear Periodic Systems via the Point Mapping Method**

H. Flashner and C.S. Hsu

TRW Space and Defense Systems Group, Redondo Beach, CA, Intl. J. Numer. Methods Engrg., 19 (2), pp 185-215 (Feb 1983) 15 figs, 3 tables, 22 refs

**Key Words:** Point mapping method

It is well known that one way to treat nonlinear periodic dynamical systems governed by ordinary differential equations is to find first the corresponding point mappings. This approach has many advantages but it has a main obstacle in that it is difficult to obtain the exact mapping except in very special cases. Presented in this paper is a procedure which allows us to determine the point mapping in a polynomial form up to any specific degree of accuracy. After presenting the algorithm for finding the point mappings, the method is applied to several problems in order to study the dynamical properties of the systems and to demonstrate the usefulness of the method.

83-1474

**Natural Rotational Modes of a Flexible Two Degree-of-Freedom Control Moment Gyroscope**

R.I. Sann

Manhattan College, Riverdale, NY, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando,

FL. Spons. Union College, Schenectady, NY, pp 698-704, 10 figs, 1 ref

**Key Words:** Gyroscopes, Modal analysis, Eigenvalue problems

This paper presents a theoretical dynamic analysis of the free rotational modes of oscillation of a two-degree of freedom control moment gyroscope, with a flexible outer gimbal. The primary concern of the analysis is to study the effect of gimbal torquer inertia on frequency and shape of the flexible gyrodynamic rotational modes of oscillation. These are the free modes which most affect the stability and closed loop bandwidth of the gyro gimbal drive servos. Based on a four degree-of-freedom mechanical model of the rotational system, equations of motion are derived, that include inertial, gyroscopic, elastic and structural damping matrices. Modal analysis leads to a complex matrix eigenvalue problem, which is solved via digital computer. The modes consist of two rigid body modes, one free gyro nutation mode, and two structural modes.

83-1475

**Longitudinal Elastic Wave Propagation in Laminated Composites with Bonds**

E.A. Nassar and A.H. Nayfeh

Mech. Engrg. Tech. Dept., Saginaw Valley State College, University Center, MI 48710, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 15-25, 7 figs, 2 tables, 7 refs

**Key Words:** Layered materials, Composite structures, Bonded structures, Wave propagation, Elastic waves, Finite element technique

The finite element displacement method is extended to study the propagation of longitudinal elastic waves in laminated composites with bonds. The geometric arrangement of the composite model considered in this paper is treated as a special type of a trilaminated composite in which each of its major constituents is sandwiched between two bonding layers. The dispersion characteristics of this model are presented here and compared with those obtained using continuum theory with microstructures.

## MODELING TECHNIQUES

83-1476

**Electrotopography - A New Tool for Modeling Dynamic Mechanical Structures**

M. Ensanian

Laboratory for Robot Sensor Technology, Ensanian Physicochemical Inst., Eldred, PA 16731, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 216-222, 4 figs, 3 tables, 4 refs

**Key Words:** Electrotopography, Mathematical models, Modal analysis

Electrotopography is a new science and technology and it is concerned with the n-dimensional physicochemical characterization of engineering components. It is based upon a new type of transducer system. The method permits one to perform a systems analysis on metallurgical structures in terms of their chemical elemental constituents. Fundamentally, this provides a new approach to modeling dynamic mechanical structures and modal analysis. This paper provides a brief overview of the new field.

**83-1477**

**Transient Load Modeling: Clipped Normal Processes**

O. Ditlevsen and H.O. Madsen

Danmarks Ingeniorakademi, Bldg. 373, DK 2800 Lyngby, Denmark, ASCE J. Engrg. Mech., 109 (2), pp 494-515 (Apr 1983) 6 figs, 26 refs

**Key Words:** Mathematical models, Transient excitation, Stochastic processes

The paper discusses the possibility of using a class of stochastic processes, called clipped normal processes, for simulating transient load effect phenomena in structures. Mean upcrossing rates of some level, for sums of clipped normal processes, can be calculated by the use of a general method calculating mean outcrossing rates of normal vector processes from convex polyhedral sets in a multi-dimensional real space. The mean upcrossing rate of a high level gives the essential term of an upper bound on the failure probability, i.e., the probability of exceeding the given level within a given time period. That this upper bound for high levels may be close to the exact failure probability is demonstrated by an example calculating a lower bound based on the bivariate distributions of the generating normal processes. Both the upcrossing rate determination and the calculation of the lower bound are based on some well-known general formulas for optimized upper and lower bounds.

**83-1478**

**Finite Element Modeling of Fluid Systems Using the Mobility Analogy Approach**

R.J. Gaines and R. Singh

Ohio State Univ., 206 W. 18th Ave., Columbus, OH 43210, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 8-10, 4 figs, 4 tables, 15 refs

**Key Words:** Fluids, Natural frequencies, Mode shapes, Finite element technique, Mobility method

One-dimensional fluid systems can be analyzed for natural frequencies and modes using an available structural finite element program, with the aid of the mobility analogy. In this paper, the methodology, strength and limitation of the solution technique are discussed. This method is validated by considering several example cases and comparing results with theory, experiment or other numerical techniques.

**83-1479**

**Optimization of Model Matrices by Means of Experimentally Obtained Dynamic Data**

W. Heylen

Katholieke Univ. Leuven, Belgium, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 32-38, 2 tables, 14 refs

**Key Words:** Mathematical models, Optimization, Experimental test data

Model optimization is a name for all techniques using experimental model parameters to modify an existing analytical model, expressed by a mass, stiffness and damping matrix. A survey is given of the various techniques reported in the literature. These techniques can be divided into two main groups: methods based essentially upon equations of motion and upon orthogonality conditions; methods using sensitivity analysis techniques. A number of particular problems are discussed - selection of the unknown structural parameters, typical limitations of the experimental data, description methods of the damping.

## NONLINEAR ANALYSIS

**83-1480**

**A Consistent Eulerian Formulation of Large Deformation Problems in Statics and Dynamics**

M.S. Gacala, G.A'E. Oravas, and M.A. Dokainish  
Ontario Hydro, Res. Div., Toronto, Ontario M8Z

5S4, Canada, Intl. J. Nonlin. Mech., 18 (1), pp 21-35 (1983) 1 fig, 37 refs

**Key Words:** Nonlinear theories

A concise survey of formulation methods of geometric and material nonlinearity problems is given. The survey is concerned mainly with the differences between updated Lagrangian and Eulerian formulations, and with the specific nature and basic characteristics of each. The underlying mechanics and the spatial discretization for an Eulerian formulation are discussed.

## NUMERICAL METHODS

(Also see No. 1361)

**83-1481**

### **The Numerical Implementation of a Multi-Input Modal Estimation Method for Mini-Computers**

H. Vold and G.T. Rocklin

Structural Dynamics Res. Corp., Milford, OH, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 542-548, 12 refs

**Key Words:** Modal analysis, Frequency response function, Curve fitting, Poly reference method, Numerical analysis

The poly reference complex exponential method has, through its application in fields such as seismic, aerospace and automotive industries been shown to handle structures with high modal density, repeated roots and high damping. Simultaneous use of data from multiple exciter locations reduces the user interaction and judgement required to obtain consistent modal models of complex structures. This paper presents various methods for numerical implementation of the poly reference technique and compares their merits for the short precision mini-computer environment.

**83-1482**

### **The Stability of Parametric Systems under Piecewise-Constant Excitation**

J. Fedorov

Ivanovskii Energeticheskii Institut im. B.I. Lenin, USSR, Vibrotehnika, 4 (34), pp 13-17 (1982) 5 figs, 4 refs  
(In Russian)

**Key Words:** Numerical analysis, Dynamic stability

Numerical analysis is used to study parametric system stability under periodic piecewise-constant excitation. The effects of damping and excitation on the instability region transformation are investigated. The results of the investigation are presented in a graphical form.

## PARAMETER IDENTIFICATION

(Also see No. 1493)

**83-1483**

### **Modeling and Identification of Mechanical Structures**

K.A.F. Moustafa

College of Engineering, Mosul Univ., Mosul, Iraq, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 671-678, 13 refs

**Key Words:** Parameter identification techniques

Mathematical models for a mechanical structural system are derived. The unknown model parameters are identified by on-line schemes that utilize excitation and response records.

**83-1484**

### **Parameter Estimation from Frequency Response Measurements Using Rational Fraction Polynomials**

M.H. Richardson and D.L. Formenti

Structural Measurement Systems, Inc., San Jose, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 167-181, 24 figs, 6 refs

**Key Words:** Parameter identification technique, Frequency response function, Rational fraction polynomials

This is a new formulation which overcomes many of the numerical analysis problems associated with an old least squared error parameter estimation technique. Overcoming these problems has made this technique feasible for implementation on mini-computer based measurement systems. This technique is not only useful in modal analysis applications for identifying the modal parameters of structures, but it can also be used for identifying poles, zeros and resonances of combined electro-mechanical servo-systems.

**83-1485**

**Estimation of Modal Parameters in a Noise-Driven Linear System by an Averaged Short-Time Fourier Technique**

D.H. Friedman

Dept. of Electrical Engrg., Rutgers Univ., P.O. Box 909, Piscataway, NJ 08854, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 123-129, 8 figs, 4 refs

**Key Words:** Parameter identification technique

A method is presented for estimating the modal parameters of a linear system from its output when driven by an inaccessible wideband noise process, based on the ratio of a short-time Fourier transform and its derivative with respect to time location. Theory indicates that the mean estimated damping factors in particular are nearly independent of relative mode amplitudes and unaffected by observation noise.

**83-1486**

**Accuracy of Modal Parameters from Modal Testing**

W. Looser

Inst. of Machine Tool Design and Production Engrg., Swiss Federal Inst. of Tech., Zurich, Switzerland, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 201-207, 12 figs, 6 refs

**Key Words:** Parameter identification technique, Modal tests, Error analysis

The accuracy of modal parameters from modal testing is of paramount importance when they are used for further calculations such as structure modifications, coupling of substructures etc. The measurement itself can be faulty, depending on type, location and intensity of excitation. Considerable differences can also occur when measurements are repeated. For structures with strong resonance coupling and high damping, identification with conventional technology places high demands. Error sources and limits in measurement and identification are shown. New procedural possibilities are also presented.

**83-1487**

**Identification of Structural Modal Parameters from Measured Multi-Station Data**

C. Yaodong, S. Dunzhi, and S. Yueming

Zhejiang Univ., Hangzhou, Zhejiang, China, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 187-191, 4 figs, 4 refs

**Key Words:** Parameter identification technique, Modal analysis, Viscous damping, Curve fitting, Machine tools

A method of identification is proposed which enables identification of modal parameters of mechanical systems with viscous damping in a wide frequency band, including a large number of modes. Theoretically, the identified frequency range and number of modes are unlimited. According to complex modal theory, the relationship between modal parameters and frequency response is formulated. Structure is excited at one point and frequency response data are measured at many stations of interest. The curve fitting is based on the least squares principle and term by term fitting is used. By using the method proposed simultaneous curve-fitting of many frequency response curves measured by forcing the structure at one point is available. The procedure has been successfully used for the dynamic investigation of a surface grinding machine.

**83-1488**

**Advanced Matrix Methods for Experimental Modal Analysis - A Multi-Matrix Method for Direct Parameter Extraction**

J.M. Leuridan and J.A. Kundrat

Structural Dynamics Res. Corp., Milford, OH, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 192-200, 15 figs, 1 table, 12 refs

**Key Words:** Parameter identification technique, Matrix methods, Modal analysis

With the multi-matrix method, a matrix polynomial is estimated using frequency responses, relative to several reference locations, simultaneously. From the matrix coefficients, a consistent set of modal parameters is calculated. Two application examples are used to show how this method, by taking full advantage of the redundancy in the frequency responses, can handle structures with various dynamic characteristics such as repeated modes, high modal damping and high modal density.

**83-1489**

**Modification and Refinement of Large Dynamic Structural Models: Efficient Algorithms and Computer Applications**

K.D. Blakely and M.W. Dobbs

ANCO Engineers, Inc., Culver City, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 598-602, 2 figs, 2 tables, 12 refs

**Key Words:** System identification techniques, Mode modification method, Off-shore structures, Drilling platforms, Dams

System identification involves the modification of a structural model to accurately reflect actual structural behavior. The model modification process is described herein, including theory and previous implementation. Current, efficient implementation, via closed-form response sensitivity calculations and design variable linking, is given. Forced-vibration testing and subsequent model modification are presented for a concrete arch dam and a steel offshore oil platform.

**83-1490**

**Integrated System Identification: The Union of Testing and Analysis**

K.D. Blakely and M.W. Dobbs

ANCO Engineers, Inc., Culver City, CA, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 259-264, 9 figs, 2 tables, 14 refs

**Key Words:** System identification techniques, Piping systems, Nuclear power plants, Containment structures, Off-shore structures

The four phases of integrated system identification - formulation and use of a pre-test analytical model, dynamic testing and data reduction, identification of model characteristics, and post-test model verification/refinement - are presented as they pertain to correlating a linear elastic finite element model to match test data. Application of each phase to model testing and analysis of large-scale structures is given. Integrated system identification, linking testing and analysis by utilizing both the analyst and experimentalist, is shown to be an effective tool in deriving accurate structural models.

**83-1491**

**Hydrodynamic Added-Mass Identification from Resonance Tests**

L. Jezequel

Ecole Centrale de Lyon, Ecully, France, AIAA J., 21 (4), pp 608-613 (Apr 1983) 1 fig, 5 tables, 18 refs

**Key Words:** Submerged structures, System identification techniques, Structural modification techniques, Experimental test data

The finite element method applied to the calculation of hydrodynamic added mass implies error and high computer cost. The proposed method aims at identifying the added mass by using the measurement of the modes of the structure, both dry and in contact with the fluid. The discrete model which expresses the dynamic behavior of the fluid structure system is obtained through an optimization procedure. The prediction of the influence of structural modification was obtained by applying the method to the case of a plate partially immersed in water.

## OPTIMIZATION TECHNIQUES

**83-1492**

**Sensitivity Analysis of Mechanical Structures, Based on Experimentally Determined Modal Parameters**

P. Vanhonacker

Leuven Measurement and Systems, Heverlee, Belgium, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 534-541, 6 figs, 18 refs

**Key Words:** Sensitivity analysis, Optimization, Dynamic response, Modal analysis, Viscous damping

As the search for optimal design or modification of linear structures becomes increasingly important, it is important to estimate efficiently the sensitivity of the dynamic behavior with respect to the changes of system parameters like mass, stiffness or damping distribution. Efficient methods for evaluating the derivatives of natural frequencies and modal displacements are proposed. Emphasis is placed on sensitivity methods which require only modal parameters as input data and in which the general viscous damping representation is used. Expressions for both differential and finite difference sensitivities of eigenvalues and eigenvectors are presented. Practical applications on the use of sensitivity analysis in prototype optimization and troubleshooting problems are presented.

## DESIGN TECHNIQUES

**83-1493**

**Optimal Redesign Based on Modal Data**

J.M. Starkey and J.E. Bernard

Michigan State Univ., East Lansing, MI, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 591-597, 6 figs, 4 tables, 4 refs

**Key Words:** Mode modification technique, Design techniques

Structural redesign problems can be classified as either prediction problems; that is, predicting new natural frequencies and mode shapes given a description of the proposed changes, or specification problems, in which details of the design change are sought which will yield desirable dynamic characteristics. This paper illustrates a technique which uses modal data as a basis for specifying an alternative design which has improved structural dynamics. The technique allows the specification of undesirable frequency bands and costs for design changes, and attempts to find a cost-effective design which removes frequencies from these bands.

## COMPUTER PROGRAMS

**83-1494**

**"PVASt" a Finite Element Program for Propeller Vibration and Strength Analysis**

D.R. Smith and M.E. Norwood

Defence Res., Establishment Atlantic, Dartmouth, Nova Scotia, Canada, Intl. Modal Analysis Conf., Proc. 1st, Nov 8-10, 1982, Orlando, FL. Spons. Union College, Schenectady, NY, pp 679-685, 14 figs, 1 table, 6 refs

**Key Words:** Computer programs, Propellers, Marine propellers, Vibration analysis

A computer program, PVASt, which has been developed for the linear elastic analysis of marine propellers is described. The program is based on the finite element method of structural analysis. It has been designed to automatically generate finite element models from a large library of elements for a wide variety of propeller geometries. Graphic displays of the geometry and the finite element model are provided for data checking purposes. The program has the ability to carry out static, natural frequency, and dynamic response analysis and to account for the effects of fluid structure interaction. Computer results are processed by the program to show stress, displacements, natural frequency of vibration and dynamic response in graphic form for ease of interpretation.

**83-1495**

**User's Manual for UCIN-EULER. A Multipurpose, Multibody Systems Dynamics Computer Program**

R.L. Huston, M.W. Harlow, and N.L. Gausewitz  
Inst. of Appl. Interdisciplinary Res., Cincinnati Univ., OH, Rept. No. ONR-UC-MIE-090182-14, 52 pp (Sept 1982)  
AD-A120 403

**Key Words:** Computer programs

This is a user's manual for the computer program UCIN-EULER. The program is designed and developed to study the dynamics of multibody systems. The multibody systems encompassed by EULER are systems of linked rigid bodies with no closed loops, such as robot arms, chains, antennas, manipulators, and human body models. The manual provides instruction for using EULER to study multibody system dynamics. It also provides sample input and output data. Input procedures and commands are expressed in terms of keywords in order to make the program useful and readily accessible to even the casual user.

## GENERAL TOPICS

### CONFERENCE PROCEEDINGS

**83-1496**

**International Modal Analysis Conference**

Proc. of the 1st, Orlando, FL. Nov 8-10, 1982. Spons. Union College, Schenectady, NY

**Key Words:** Modal analysis, Proceedings

The latest theories, research activities, and practical applications of experimental modal analysis techniques were presented at this conference. Dozens of papers are devoted entirely to analytical methods and dozens more to experimental techniques and case histories. Considerable emphasis is given to the latest efforts to link analysis and experiment through their respective computers, thereby blurring the boundary between traditionally separate disciplines.

### USEFUL APPLICATIONS

**83-1497**

**A Method for Measuring the Mass Concentration of Solid Particles in Fluids with the Aid of Transversally Vibrating Filter Bands (Massenbestimmung disperser Stoffe mit Hilfe transversal schwingender Filterbänder)**

H. Bahner and Th. Gast  
Auguste-Viktoria-Str. 4, 1000 Berlin 33, Techn.  
Messen-TM, 50 (1), pp 3-13 (Jan 1983) 14 figs,  
1 table, 14 refs  
(In German)

**Key Words:** Measurement techniques, Fluids, Vibratory  
techniques, Filters (mechanical)

A method for measuring the mass concentration of solid  
particles in fluids with the aid of transversally vibrating

filter bands is described. The precipitated particles contribute to the mass of the filter and affect its natural frequency. Thus, a comparison between the respective frequencies of a fresh and an exposed filter allows to calculate the mass concentration of the particulate matter. The method provides absolute values which are independent of the chemical or physical composition of the solid. In this regard it needs no empirical correction. Suitable filter materials have been selected and their vibrational behavior has been tested.

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## AUGUST 1983

- 8-11 Computer Engineering Conference and Exhibit [ASME] Chicago, IL (ASME Hqs.)
- 8-11 West Coast International Meeting [SAE] Vancouver, B.C. (SAE Hqs.)

## SEPTEMBER 1983

- 11-13 Petroleum Workshop and Conference [ASME] Tulsa, OK (ASME Hqs.)
- 11-14 Design Engineering Technical Conference [ASME] Dearborn, MI (ASME Hqs.)
- 12-15 International Off-Highway Meeting & Exposition [SAE] Milwaukee, WI (SAE Hqs.)
- 14-16 International Symposium on Structural Crashworthiness [University of Liverpool] Liverpool, UK (Prof. Norman Jones, Dept. of Mech. Engrg., The Univ. of Liverpool, P.O. Box 147, Liverpool L69 3BX, England)
- 25-29 Power Generation Conference [ASME] Indianapolis, IN (ASME Hqs.)
- 28-30 Rotating Machinery Vibration Symposium [Vibration Institute] Worcester, MA (Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254)

## OCTOBER 1983

- 3-7 Advances in Dynamic Analysis and Testing [SAE Technical Committee G-5] SAE Aerospace Congress and Exposition, Long Beach, CA (Roy W. Mustain, Rockwell Space Transportation and Systems Group, Mail Sta. AB97, 12214 Lakewood Blvd., Downey, CA 90241)
- 3-7 SAE Aerospace Congress and Exposition [SAE] Long Beach, CA (SAE Hqs.)
- 17-19 Stepp Car Crash Conference [SAE] San Diego, CA (SAE Hqs.)
- 17-20 Lubrication Conference [ASME] Hartford, CA (ASME Hqs.)
- 18-20 54th Shock and Vibration Symposium [Shock and Vibration Information Center, Washington, DC]

Pasadena, CA (Mr. Henry C. Pusey, Director, SVIC, Naval Research Lab., Code 5804, Washington, DC 20375)

- 31-Nov 4 John C. Snowdon Vibration Control Seminar [Applied Research Lab., Pennsylvania State Univ.] University Park, PA (Mary Ann Solic, 410 Keller Conference Center, University Park, PA 16802 - (814) 865-4591)

## NOVEMBER 1983

- 6-10 Truck Meeting and Exposition [SAE] Cleveland, OH (SAE Hqs.)
- 7-11 Acoustical Society of America, Fall Meeting [ASA] San Diego, CA (ASA Hqs.)
- 13-18 American Society of Mechanical Engineers, Winter Annual Meeting [ASME] Boston, MA (ASME Hqs.)

## MARCH 1984

- 20-23 Balancing of Rotating Machinery Symposium [Vibration Institute] Philadelphia, Pennsylvania (Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254)

## APRIL 1984

- 9-12 Design Engineering Conference and Show [ASME] Chicago, IL (ASME Hqs.)
- 9-13 2nd International Conference on Recent Advances in Structural Dynamics [Institute of Sound and Vibration Research] Southampton, England (Dr. Maurice Petyt, Institute of Sound and Vibration Research, The University of Southampton, SO9 5NH, England - (0703) 559122, ext. 2297)

## MAY 1984

- 7-11 Acoustical Society of America, Spring Meeting [ASA] Norfolk, VA (ASA Hqs.)
- 10-11 12th Southeastern Conference on Theoretical and Applied Mechanics [Engineering Extension Service, Auburn University, Alabama] Callaway Gardens, Pine Mountain, GA (J. Fred O'Brien, Director, Engineering Extension Service, Auburn University, AL 36849 - (205) 826-4370)

# CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AHS:	American Helicopter Society 1325 18 St. N.W. Washington, D.C. 20036	IFTOMM:	International Federation for Theory of Machines and Mechanisms U.S. Council for TMM c/o Univ. Mass., Dept. ME Amherst, MA 01002
AIAA:	American Institute of Aeronautics and Astronautics 1290 Sixth Ave. New York, NY 10019	INCE:	Institute of Noise Control Engineering P.O. Box 3206, Arlington Branch Poughkeepsie, NY 12603
ASA:	Acoustical Society of America 335 E. 45th St. New York, NY 10017	ISA:	Instrument Society of America 400 Stanwix St. Pittsburgh, PA 15222
ASCE:	American Society of Civil Engineers 345 E. 45th St. New York, NY 10017	SAE:	Society of Automotive Engineers 400 Commonwealth Drive Warrendale, PA 15096
ASME:	American Society of Mechanical Engineers 345 E. 45th St. New York, NY 10017	SEE:	Society of Environmental Engineers Owles Hall, Buntingford, Hertz. SG9 9PL, England
ASTM:	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103	SESA:	Society for Experimental Stress Analysis 21 Bridge Sq. Westport, CT 06880
ICF:	International Congress on Fracture Tohoku University Sendai, Japan	SNAME:	Society of Naval Architects and Marine Engineers 74 Trinity Pl. New York, NY 10006
IEEE:	Institute of Electrical and Electronics Engineers 345 E. 47th St. New York, NY 10017	SPE:	Society of Petroleum Engineers 6200 N. Central Expressway Dallas, TX 75206
IES:	Institute of Environmental Sciences 940 E. Northwest Highway Mt. Prospect, IL 60056	SVIC:	Shock and Vibration Information Center Naval Research Lab., Code 5804 Washington, D.C. 20375
IMechE:	Institution of Mechanical Engineers 1 Birdcage Walk, Westminster, London SW1, UK		

## PUBLICATION POLICY

Unsolicited articles are accepted for publication in the Shock and Vibration Digest. Feature articles should be tutorials and/or reviews of areas of interest to shock and vibration engineers. Literature review articles should provide a subjective critique/summary of papers, patents, proceedings, and reports of a pertinent topic in the shock and vibration field. A literature review should stress important recent technology. Only pertinent literature should be cited. Illustrations are encouraged. Detailed mathematical derivations are discouraged, rather, simple formulas representing results should be used. When complex formulas cannot be avoided, a functional form should be used so that readers will understand the interaction between parameters and variables.

Manuscripts must be typed (double-spaced) and figures attached. It is strongly recommended that line figures be rendered in ink or heavy pencil and neatly labeled. Photographs must be unscreened glossy black and white prints. The format for references shown in DIGEST articles is to be followed.

Manuscripts must begin with a brief abstract, or summary. Only material referred to in the text should be included in the list of References at the end of the article. References should be cited in text by consecutive numbers in brackets, as in the example below.

Unfortunately, such information is often unreliable, particularly statistical data pertinent to a reliability assessment, as has been previously noted [1].

Critical and certain related excitations were first applied to the problem of assessing system reliability almost a decade ago [2]. Since then, the variations that have been developed and the practical applications that have been explored [3-7] indicate that...

The format and style for the list of References at the end of the article are as follows:

- each citation number as it appears in text (not in alphabetical order)
- last name of author/editor followed by initials or first name
- titles of articles within quotations, titles of books underlined

- abbreviated title of journal in which article was published (see Periodicals Scanned list in January, June, and December issues)
- volume, number or issue, and pages for journals; publisher for books
- year of publication in parentheses

A sample reference list is given below.

1. Pletzer, M.F., "Transonic Blade Flutter - A Survey," Shock Vib. Dig., 7 (7), pp 97-106 (July 1975).
2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.L., Aeroelasticity, Addison-Wesley (1955).
3. Jones, W.P., (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Devel. (1962).
4. Lin, C.C., Ralston, E., and Tsien, H., "On Two-Dimensional Nonsteady Motion of a Slender Body in a Compressible Fluid," J. Math. Phys., 27 (3), pp 220-231 (1948).
5. Landahl, M., Unsteady Transonic Flow, Pergamon Press (1961).
6. Miles, J.W., "The Compressible Flow Past an Oscillating Airfoil in a Wind Tunnel," J. Aeronaut. Sci., 23 (7), pp 671-678 (1956).
7. Lane, F., "Supersonic Flow Past an Oscillating Cascade with Supersonic Leading Edge Locus," J. Aeronaut. Sci., 24 (1), pp 65-68 (1957).

Articles for the DIGEST will be reviewed for technical content and edited for style and format. Before an article is submitted, the topic area should be cleared with the editors of the DIGEST. Literature review topics are assigned on a first come basis. Topics should be narrow and well-defined. Articles should be 1500 to 2500 words in length. For additional information on topics and editorial policies, please contact:

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